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ON THE CONDITIONS WHICH AFFECT THE SPECTRO-PHOTOGRAPHY OF THE SUN.

By ALBERT A. MICHELSON.

THE recent developments in solar spectro-photography are in great measure due to the device originally suggested by Janssen and perfected by Hale and Deslandres, by means of which a photograph of the Sun's prominences may be obtained at any time as readily as it is during an eclipse. The essential features of this device are the simultaneous movements of the collimator-slit across the Sun's image, with that of a second slit (at the focus of the photographic lens) over a photographic plate. If these relative motions are so adjusted that the same spectral line always falls on the second slit, then a photographic image of the Sun will be reproduced by light of this particular wavelength.

Evidently the process is not limited to the photography of the prominences, but extends to all other peculiarities of structure which emit radiations of approximately constant wavelength; and the efficiency of the method depends very largely upon the *contrast* which can be obtained by the greater enfeeble-

ment of the background of white light, by dispersion, as compared with the relatively fixed intensity of the homogeneous radiations.

An aid to the practical realization of the method, whose importance can hardly be overestimated, consists in the use of the bright H and K lines for this purpose; their exceptional efficiency depending upon the fact that the continuous spectrum in their immediate vicinity is already very much reduced by broad absorption bands.

In addition to this contrast, it is of course necessary that the actual intensity of the light should be sufficient to affect the photographic plate, and also that the outline and details should be as sharply defined as the photographic process and other conditions permit. These conditions and their effects upon these essential circumstances we now proceed to investigate.

Let s = width of collimator slit,

h = length of the image of a prominence,

s_2 and h_2, their spectral images,

$\beta = \frac{d}{f}$ = aperture of objective,

$\beta_1 = \frac{d_1}{f_1}$ = aperture of collimator,

$\alpha = \frac{d_2}{f_2}$ = aperture of photographic lens,

ϕ_1 = angle of incidence,

ϕ_2 = angle of diffraction,

$\sigma = \frac{d_1}{-}$ = grating space,

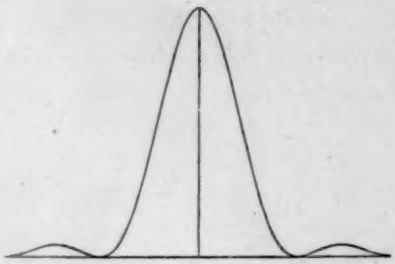
m = order of spectrum.

If the whole aperture of the collimator is filled with light by the cone of rays from the objective, then $\beta_1 = \beta$. The magnification of the spectroscope is $\frac{f_2}{f_1}$; and there is a further enlargement due to diffraction by the aperture of the photographic lens (to which should be added the effects of imperfections in the lenses and gratings or prisms, of vibrations and of inequalities of temperature); and, finally, the enlargement by dispersion.

Supposing the effective aperture to be square,[1] the effect of diffraction, the source being a point, is given by the formula $I = \frac{\sin^2 \Phi}{\Phi^2}$, in which $\Phi = \frac{\pi}{\lambda} \alpha x$, x being the distance from the geometrical image.

This is shown graphically in the figure, in which the ordinates represent intensity and the abscissæ the angle Φ.

The actual width of the line is that for which $\Phi = 2\pi$; that is, $x_1 = 2\frac{\lambda}{\alpha}$; but the apparent width will vary with the sensitiveness of the eye, or the photographic plate.



In the case of a source of finite width, the effect would be found by integrating this expression between values corresponding to the width of the source. In any case the geometrical image is broadened by a quantity $\epsilon\frac{\lambda}{\alpha}$, in which (in view of the uncertainty just noted, and considering also that the various disturbing elements previously noted make the actual value still more vague) ϵ may represent a factor which lies between 1.5 and 2.0.

We have next to investigate the dispersion, and for this purpose it will be convenient to assume that it is produced by a grating. Suppose the light of the source to have a range of wave-length $\delta\lambda$. The dispersion will then be $\frac{d\phi}{d\lambda}\delta\lambda$. But

$$\frac{d\phi}{d\lambda} = \frac{m}{\sigma \cos \phi_2} \;,$$

[1] The result for a circular aperture would be to increase the width one-fourth.

and substituting for σ its value, we have for the enlargement due to dispersion

$$f_2 \frac{m n \delta \lambda}{d_1 \cos \phi_2}.$$

Remembering that the effective aperture of the photographic lens is $d_2 \cos \phi_2$, d_2 being the length of the grating which is covered by the incident light; and that $d_2 = \frac{d_1}{\cos \Phi_1}$, we obtain for the width of the spectral image of a slit of width s the expression

$$s_2 = \frac{f_2}{f_1} s + \epsilon f_2 \frac{\lambda \cos \phi_1}{d_1 \cos \phi_2} + f_2 \frac{m n \delta \lambda}{d_1 \cos \phi_2}.$$

For our present purpose it will not be necessary to include the effect of the angles ϕ_1 and ϕ_2, which we may suppose so small that their cosines are nearly equal to unity.

Substituting for $\frac{d_1}{f_1}$ its approximate value β, and for $\frac{f_2}{f_1}$ its approximate value $\frac{\beta}{a}$ we have

$$s_2 = \frac{1}{a}(\beta s + \epsilon \lambda + m n \delta \lambda). \tag{1}$$

If the intensity of the source (diminished by absorption through the atmosphere) be represented by unity, and e represent a factor depending on losses in the spectroscope other than those due to diffraction, dispersion and magnification, then we have for the intensity of the spectral image

$$i = \frac{e}{2} \sin^2 \frac{\beta}{2} \frac{s h}{s_2 h_2},$$

or very nearly
$$i = \frac{e a^2 \beta^2 s h}{8 (\beta h + \epsilon \lambda)(\beta s + \epsilon \lambda + m n \delta \lambda)}. \tag{2}$$

If we may extend the assumption that the intensity of a spectral "line" is inversely proportional to the ratio of its breadth to the entire effective portion of the spectrum, then supposing the background to be p times as bright as the approximately monochromatic source, we have for the ratio of intensities the expression

$$r = \frac{i_w}{i} = p \frac{\beta s + \epsilon \lambda + m n \delta \lambda}{\beta s + \epsilon \lambda + m n (\lambda_1 - \lambda_2)},$$

or nearly,
$$r = \frac{p}{\lambda_1 - \lambda_2}\left(\frac{\beta s + \epsilon \lambda}{m n} + \delta \lambda\right). \tag{3}$$

λ_1 and λ_2 being the limits of the effective portion of the spectrum. From this it appears that it will be of advantage to increase the dispersion $(m\,n)$ until

$$\beta s + \epsilon\lambda = \tfrac{1}{2} m\,n\,\delta\lambda. \tag{4}$$

It is therefore important that the first slit should be narrow; but no great advantage will be gained when $s < \frac{1}{2}\frac{\epsilon\lambda}{\beta}$, while beyond this point light is lost by the diffracted rays falling outside the collimator.

With the above value of $m\,n\,\delta\lambda$ we have $r = \frac{3}{2}p\frac{\delta\lambda}{\lambda_1 - \lambda_2}$.

By doubling this dispersion the ratio r would only be reduced in the proportion of 5 : 6, while the loss in sharpness and brightness would much more than compensate for this slight increase in contrast.

These effects we now proceed to investigate.

The sharpness of the photographic image (supposing the focusing to be exact and the effects of irradiation negligible) will depend on the distinctness of the spectral image which falls on the second slit. This slit should be narrow (simply to protect the parts of the plate where there is no image, but merely the spectrum of the white background), but no important advantage will be gained by making the width less than that of the image of the first slit.

The sharpness of detail in the spectral image is independent of the slit-width, except in so far as this entails increased dispersion in order to maintain contrast.

If the source were a line, its first image would have a width[1] $\frac{\epsilon\lambda}{\beta}$. This image is magnified by the spectroscope in the proportion $\frac{\beta}{\alpha}$, and is further enlarged[2] by the quantity $\frac{1}{\alpha}(\epsilon\lambda + m\,n\,\delta\lambda)$; so that the actual hazy border may be measured by

[1] Disregarding the accidental sources of indistinctness already mentioned.

[2] The expression for the increase in width due to dispersion assumes that within the limits λ to $\lambda + \delta\lambda$ the intensity is constant.

In view of the uncertainties mentioned above, together with the difficulty in ascertaining the true distribution of intensity as a function of λ, it seems scarcely worth while to perform the double integration which would lead to the more accurate expression.

$$w = \frac{1}{a}(2\epsilon\lambda + mn\delta\lambda). \tag{5}$$

If the slit have the minimum efficient width $\left(s = \frac{1}{2}\frac{\epsilon\lambda}{\beta}\right)$ then the most suitable dispersion is $mn\delta\lambda = 3\epsilon\lambda$, which gives $w_1 = \frac{5\epsilon\lambda}{a}$; so that the effect of dispersion in this case is to increase the border-width 2½ times. This increased width is, however, only about $0^{mm}.038$, which in a 50 to 100^{mm} disk may be safely ignored.

If, however, the slit be as wide as $0^{mm}.4$, the dispersion $mn\delta\lambda$ would have to be increased to $0^{mm}.0415$ to maintain the contrast, and w would then be over $0^{mm}.40$, an amount of indistinctness which would make a poor image.

For the absolute brightness (supposing the prominence to cover the whole width of the slit) we have

$$i = \frac{\epsilon a^2 \beta^2 s h}{24(\beta h + \epsilon\lambda)(\beta s + \epsilon\lambda)},$$

which shows that the effect of the given dispersion is to diminish the intensity to one-third of the value it would have with zero dispersion. This is not, however, so serious a loss as to make it worth while to sacrifice any of the contrast; but this would hardly be true with four times as great a dispersion, for in that case the intensity would have only one-ninth its maximum value.[1]

The conditions for the limit of useful dispersion are given by the formula

$$mn\delta\lambda = 2(\beta s + \epsilon\lambda).$$

If the first slit be so narrow that βs may be neglected beside $\epsilon\lambda$ (for instance, if $s < 0^{mm}.005$), then $mn = \frac{2\epsilon\lambda}{\delta\lambda} = \frac{15000}{\delta\lambda}$ in tenth-meters.

Thus, if $\delta\lambda = 0.25$ tenth-meters (which is about the "width" of the reversed calcium lines), $mn = 60{,}000$; so that, if the grat-

[1] The formula shows how important it is that a, the aperture of the photographic lens, should be as large as possible. Without any losses by reflection, absorption or dispersion, the maximum intensity of the image is $i_m = \frac{1}{8}a^2$, and since it is practically impossible to make $a > \frac{1}{5}$, we have $i_m = \frac{1}{200}$. The inevitable losses in any instrument with high dispersion would reduce this value ten times; so that with the effect of dispersion it is not likely that i should ever exceed $\frac{1}{6000}$.

	mn=100000 w=0.04 mm			mn=200000 w=0.065 mm			mn=400000 w=0.115 mm			mn=800000 w=0.215		
s	s_2	r/p	800 i/e	s_2	r/p	800 i/e	s_2	r/p	800 i/e	s_2	r/p	800 i/e
0.00	.0325	.00013	.00	.0575	.00011	.00	.1075	.00011	.00	.2075	.00010	.00
0.01	.0375	.00015	.13	.0625	.00012	.08	.1125	.00011	.04	.2125	.00011	.02
0.05	.0575	.00023	.43	.0825	.00016	.30	.1325	.00013	.19	.2325	.00012	.11
0.10	.0825	.00033	.60	.1075	.00022	.46	.1575	.00016	.31	.2575	.00013	.19
0.50	.2825	.00113	.88	.3075	.00062	.81	.3575	.00036	.70	.4575	.00023	.54
1.00	.5325	.00213	.94	.5575	.00112	.90	.6075	.00061	.82	.7075	.00035	.70
2.00	1.0325	.00413	.97	1.0575	.00212	.95	1.1075	.00111	.90	1.2075	.00060	.83

ing have 60,000 lines, the first spectrum would give sufficient dispersion.

If, however, the slit be so wide that $\epsilon\lambda$ may be neglected, then $mn = \frac{2\beta s}{\delta\lambda}$, or, supposing $\beta = \frac{1}{20}$, $mn = \frac{0.1\, s}{\delta\lambda}$.

Thus suppose $s = 0^{mm}.1$, then

$$mn = 4 \times 10^5.$$

That is, a grating of 100,000 lines, in the fourth spectrum, would just suffice to give the necessary dispersion. For a still larger slit, it would be practically impossible to use too high a dispersion; but as shown above the indistinctness of the image under these circumstances would border on the limits of toleration.

If in the preceding formulæ we substitute

$$\lambda_1 - \lambda_2 = 2500 \text{ tenth-meters},$$
$$\delta\lambda = 0.25 \text{ tenth-meters},$$
$$\beta = .05,\ a = .10,\ \epsilon = 1.5,\ \lambda = 0^{mm}.0005,$$

we get for the width of the spectral line

$$s_2 = .5\, s + .0075 + .25 \times 10^{-6} mn;$$

for the ratio

$$\frac{r}{p} = \frac{200 s + 3}{mn} + .0001;$$

for the intensity

$$800 \frac{i}{e} = \frac{s}{s + .015 + 5 \times 10^{-7} mn};$$

and for the width of hazy border

$$w = .015 + 2.5 \times 10^{-7} mn.$$

From these formulæ the accompanying table was computed.

If the dispersion is produced by a train of prisms instead of a grating, we have only to substitute for $\frac{mn}{d_1}$ in these

expressions, the equivalent value for the dispersion of a prism; namely, $\frac{d\mu}{d\lambda}\frac{t}{d_1}$, in which μ is the index of refraction, and t the difference in thickness of glass traversed by the extreme rays. If the prisms are of 60° then t is roughly $2pd_1$, p being the number of prisms; and in this case the dispersion is $2p\frac{d\mu}{d\lambda}$.

For the ordinary varieties of flint glass $\frac{d\mu}{d\lambda}$ is about 2×10^{-5}, if $d\lambda$ is expressed in tenth-meters. If the grating space $\frac{d_1}{n}$ (suppose $0^{mm}.0025$) be expressed in the same units, then for equal dispersion $4 \times 10^{-5} p = 4 \times 10^{-5} m$; or the number of prisms is equal to the order of the spectrum.

It will be of interest to compare the intensities of the grating spectrum with that of the equivalent train of prisms. If the grating acts by opacity alone (see Lord Rayleigh's article on Wave Theory of Light in *Enc. Brit.*), then the maximum brightness of the mth spectrum is $\frac{1}{m^2\pi^2}$ of the incident light. On the other hand if ρ represents the fraction of incident light which is transmitted by a single prism, then the intensity of the light which has passed through p prisms is ρ^p;[1] and if these are to be the same we have $\rho^p = m^{-2}\pi^{-2}$.

The fraction ρ varies considerably with the material and the construction of the prism. It will be somewhere near the average (though probably under rather than over), if it is placed at 0.5; in which case we have approximately $2^p = 10\,m^2$.

Suppose the grating to contain 400 lines to the mm. Then as just found, $p=m$; and the equation is nearly satisfied if $p=10$. Accordingly, as many as ten prisms might be employed before the superiority of the higher orders of spectra would be manifest. If the grating has 800 lines to the mm, $p = 2\,m$, and the advantage would be with the prisms up to $p = 7$; while for $n_1 = 1200$ lines to the mm (which has been found by experience to be near the practical limit of efficiency), $p = 3m$ and the equation is most nearly satisfied by $p = 3$.

[1] Professor Pickering has pointed out that this loss is considerably diminished in consequence of the partial polarization of the transmitted light.

It will be noted that in every case the prisms have the advantage up to the highest observable spectrum of the grating. This depends of course on the value assumed for ρ, which is in many cases undoubtedly too low. On the other hand, it is well known that the law given for the intensity of the grating spectra holds only when it acts by opacity; while in fact gratings are now made which throw a much larger proportion of light into some one spectrum.

It appears on the whole that there is little ground for a choice. It may be noted, however, that while in the case of the grating the theoretical limit is nearly reached, the prism is capable of still further improvement in the direction of material having great transparency and homogeneity, together with high dispersion.

In the practical application of the principles here discussed, many difficulties may arise owing to peculiarities of photographic processes. Thus if the plates, or the process of developing, employed be very sensitive to small differences in intensity when the light is bright, some of the "contrast" may be sacrificed. On the other hand, if the plates are nearly equally sensitive through a considerable range of small intensities, then the object should be to gain in contrast by increasing the dispersion, even at the cost of brightness—until the sharpness of the image begins to deteriorate.

Here again it is possible that the structure of the film may define the limiting condition, either by the coarseness of its grains, or by the amount of spreading of the photographic effect by irradiation.

PHOTOGRAPHS OF THE MILKY WAY.

By E. E. Barnard.

In my photographic survey of the Milky Way with the 6-inch Willard lens of this Observatory, I have come across many very remarkable regions. Some of these, besides being remarkable for showing the peculiar structure of the Milky Way, are singularly beautiful as simple pictures of the stars. I have selected two of these for illustration in The Astrophysical Journal.

THE REGION OF MESSIER 11.

(Frontispiece.)

Every telescopic observer is familiar with the beautiful cluster known as Messier Eleven (R. A. 18^h 45^m; Dec. S. 6° 24′), for it is an easy object with almost any instrument. With a low power on a considerable telescope M. 11 is one of the prettiest clusters in the sky. It is a rather open non-condensed cluster of 11–12 magnitude stars grouped about a 9 magnitude star, and covering a space of about 10′ or 12′. Like the larger and denser clusters, this also has vacant spaces in it.

From its great beauty with a low power on the 12-inch, I have often shown it to visitors here on Saturday nights. From an optical illusion, they have invariably seen "millions of stars in it."

However, there is not a vast number of stars actually composing this cluster, and it would not be a difficult task to count them. One remarkable thing in connection with the expressions of the visitors when looking at M. 11 is that a considerable percentage of them instinctively call attention to the form of the cluster itself as being that of a star. In my experience thus, I think there will have been from fifty to one hundred people who have independently exclaimed at its stellar form.

In the telescope, the cluster itself is seen to be projected on a uniform background of very small stars, and anyone examining

the region about it would not be specially impressed with the neighborhood. But looking along the telescope tube one sees that it is placed in one of the great luminous clouds of the Milky Way.

In my work on the Milky Way this cloud was one of the first objects photographed, and I have several pictures of it, the finest of which I herewith present to the readers of THE ASTROPHYSICAL JOURNAL.

Let us examine this picture carefully. The plate has taken in the entire cloud that had been seen with the naked eye. The scale of the picture is small, consequently M. 11 itself is simply a spot of light—the individual stars not being seen separately. It is seen to occupy the upper north edge of the great naked-eye cloud, and appears like a nucleus to that object. I think it hardly questionable but that M. 11 is really a nucleus to the greater cluster, though it may be only a simple case of projection.

The naked-eye cloud itself, however, becomes on the photographic plate a vast and gorgeous cluster of stars. It is shown to be an immense irregular cluster of apparently very small stars, and is seemingly perfectly isolated from the rest of the Milky Way.

In looking at this picture several people have called attention to the fact that when held in certain positions, the outline of this star cloud has a decided resemblance to some pictures of the great nebula of Orion. To the west of M. 11 the star cloud is brightest and most definite in form, with several detached outlying portions.

Running southerly from M. 11 is a broad curving semi-vacancy. About $3°$ south and west of M. 11—from a large semi-vacant region—two similar partial vacancies run divergingly eastward, and, joining the first mentioned dark stream from M. 11, form a distinct △. The northern of these thin streams partially cuts off the brightest mass of the cloud to the west of M. 11.

In looking at this picture, I have often received the impression that this huge cloud of stars had been generated by some tremendous whirling motion.

There are other curious and interesting features shown on this picture, such as vacancies and lines of stars; though I must confess that there is a marked absence here of the geometrical lines and curves that form such a striking feature in other portions of the Milky Way. Indeed, it seems to be a fact that this geometrical arrangement of the stars is more or less absent in all the definite clouds of stars, and is remarkably conspicuous in the larger uniform areas.

THE MILKY WAY NEAR CHI CYGNI.

(Plate II.)

I have before, elsewhere, called attention to the fact that the Milky Way does not anywhere repeat itself. That is, there are no two parts of the Milky Way that seem to be made up on the same plan.

Certain regions are formed by coarse stars mainly. Such is the region east and north of Orion, where these coarse stars are nearly uniformly scattered. Again, there are the great cloud regions where the massing clouds are made up uniformly of extremely small stars—that is the stars are apparently, and I believe are really very small. Such for instance are the great clouds in Sagittarius in R. A. 18^h; Dec. S. 28°.

This region near Chi Cygni seems to be made up of a background of fairly small stars with a decided sprinkling of larger and coarser ones.

The picture divides itself diagonally into two regions. The northwest half is a dense matting of small stars too thick and too dense to be seen through—forming thus a perfect veil over that part of the sky. This suddenly shoals diagonally along the middle of the plate and leaves the southeast portion covered uniformly with a thin sheeting of small stars, through which we readily look out into the blackness of space beyond. In this thin region one easily picks out the geometrical tracery, which is seemingly made up of a vast number of vacant paths among the stars.

A little to the west of the center a great semi-vacancy is seen in the dense region of stars; this has a parabolic form and runs

PLATE II

NORTH

EAST

WEST

SOUTH

PHOTOGRAPH NEAR CHI CYGNI

1892, October 20, $6^h\ 47^m - 11^h\ 47^m$ Pacific Standard Time

Taken by E. E. BARNARD with the 6-inch Willard Lens of the Lick Observatory

southwesterly. About one degree above this and slightly to the west is a curious small and sharply defined △ shaped semi-vacancy. The star Chi occupies a position about the middle of the plate, and from its reddish color is lost among the small stars, though it is easily found with a diagram. The bright star in the northeast corner of the plate is γ Cygni. This star is surrounded by great masses of nebulosity on the original plate; but to bring out the peculiar structure of the Milky Way itself in this region it was necessary to neglect the nebulosity, which to be well shown would require another positive from the same negative.

In examining this plate one will see, also, that the geometrical patterns of this part of the sky are also carried over on to the dense matting of stars occupying the westerly part of the plate, though they are more marked to the east, where the stars are thinly distributed.

Looking at these two pictures, one who is familiar with these two regions telescopically, cannot help but marvel at the wonderful power of the photographic plate over that of the eye and the telescope alone, in dealing with that magnificent zone of stars—the Milky Way.

MT. HAMILTON, Dec. 12, 1894.

THE ARC-SPECTRA OF THE ELEMENTS. I.

BORON AND BERYLLIUM.

By Henry A. Rowland and Robert R. Tatnall.

This paper is intended as a preliminary notice of a series of investigations on the arc-spectra of certain of the elements which have not hitherto been carefully studied by modern methods. The investigations may be regarded as a continuation of the work upon the solar spectrum commenced several years ago by one of us, inasmuch as the ultimate object in view is the identification of some of the many lines in the spectrum of the Sun, whose origin still remains unknown.

That portion of the work here described will be confined to the visible and ultra-violet portions of the spectrum. The infra-red portion forms the subject of another investigation which is now being carried on in this laboratory, the results of which are expected to appear later on.

The plates to be used will be for the most part selected from the series made some years since in connection with the study of the solar spectrum.[1] They are mostly 19 inches in length, and were made with a six-inch concave grating of 21½ feet radius, ruled with 20,000 lines to the inch. They comprise spectra of nearly all known elements, in both first and second orders, the latter being accompanied with the solar spectrum for purposes of comparison, according to the well-known method of Rowland.[2]

In studying the spectrum of any element, it is first necessary to eliminate all lines due to impurities by a careful comparison

[1] The completeness of this set of plates is partly due to financial aid received from the Bache Fund of the National Academy of Sciences, from the fund given by Miss Bruce to the Harvard Astronomical Observatory for the prosecution of astrophysical research, and from the Rumford Fund of the American Academy of Arts and Sciences.

[2] See Ames: "The Concave Grating in Theory and Practice," *A. and A.* **11**, 28, 1892.

with the spectra of the carbon poles, and of all elements likely to be associated with the substance under examination. This comparison is made by direct superposition of the plates, which are all to nearly the same scale, thus insuring almost perfect coincidence of corresponding lines.

The measuring engine employed has a nearly perfect screw, made according to Rowland's method,[1] with such a pitch as to measure wave-lengths directly in ten-millionths of a millimeter, a slight correction only being necessary, which depends upon the plate, and its position on the carriage of the engine.

The basis of all the measurements is the Table of Standard Wave-Lengths.[2] As a means of determining the correction to be applied in each case, numerous standard lines selected from the Table are measured, in addition to those of the element which is being studied. Many of these standards occur on every plate, due to impurities in the carbon poles or in the material introduced into them. From the standards a correction-curve is plotted for each plate, due attention being given to the weights assigned in the Table, and to the character of the lines as affecting the accuracy of setting the cross-wires upon them. Corrections derived from the curve are then applied to the lines whose wave-lengths are required. The final value for the wave-length of any line is usually the weighted mean of several independent measurements, frequently upon different plates, and in the spectra of both first and second orders.

The intensities given in the tables are estimated, in the case of the arc-spectra, upon an ascending scale from 1 to 1,000, in which 1 indicates a line so faint as to be *just* plainly visible on the plates.

Notes marked (R) are by Professor Rowland.

The intensities assigned to lines in the Sun, where these exist, are rather uncertain estimates, in which as a means of reference D_2 is taken as 300, and the Ni line at 5893.1, at 60.

[1] See *Encyclopædia Britannica*, Art. "Screw."

[2] ROWLAND: "A New Table of Standard Wave-Lengths." *A. and A.* **12**, 321, 1893.

BORON.

(*Preliminary;—w.-l. 2100 to 4400*).

Wave-Length	Intensity and Character	Remarks	Intensity in Sun
2496.867	65 r[1]		
2497.821	80 r		

Within the assigned limits, these two lines, forming a pair (given in the Table of Standard Wave-Lengths), appear to be the only representatives of the line-spectrum of boron, although the whole region is more or less densely filled with a band-spectrum, probably due to a compound such as boracic acid.

BERYLLIUM.

(*Preliminary;—w.-l. 2100 to 4600*).

Wave-Length	Intensity and Character	Remarks	Intensity in Sun
2175.072[2]	2		
2348.697	50 r	Possibly double, with components 0.346 apart.	
2350.855	7		
2494.532	40 } d s		
2494.960	40 } d s		
2650.414	45 } d s		
2651.042	45 } d s		
2898.352[2]	1		
2986.187[2]	3 }		
2986.546[2]	2 }		
3130.546	60 }	Coincides with a fine line in the Sun (R).	4[3]
3131.194	60 }	Coincides with one-half of a broader solar line.	5 n
3321.219	45 }	The latter is therefore probably double (R).	
3321.487	45 }		
3367.719[2]	3 n		
4572.869	45 s		

[1] r indicates *reversed*.

[2] Possibly not due to beryllium.

[3] On this scale the standard Zr line λ 3129.882 has the intensity 3.

r indicates *reversed*.

d indicates *double*.

s indicates *sharp*.

n indicates *hazy* or *nebulous*.

A few faint lines, difficult to identify, and indicated thus (²), do not *certainly* belong to beryllium. As a rule these do not occur in the second order spectrum. A careful comparison with the spectra of elements likely to be associated with beryllium has shown that they do not belong to C, Si, Ca, Al, Fe, Mn, Mg, Sn, As, Ce.

JOHNS HOPKINS UNIVERSITY,
November 28, 1894.

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2494.532	40 d s		
2494.960	40 s		
2650.414	45 d s		
2651.042	45 s		
2898.352[2]	1		
2986.187[2]	3		
2986.546[2]	2		
3130.546	60	Coincides with a fine line in the Sun (R).	4 [3]
3131.194	60	Coincides with one-half of a broader solar line.	5 n
3321.219	45	The latter is therefore probably double (R).	
3321.487	45		
3367.719[2]	3 n		
4572.869	45 s		

[1] r indicates *reversed.*
[2] Possibly not due to beryllium.
[3] On this scale the standard Zr line λ 3129.882 has the intensity 3.
r indicates *reversed.*
d indicates *double.*
s indicates *sharp.*
n indicates *hazy* or *nebulous.*

A few faint lines, difficult to identify, and indicated thus ([2]), do not *certainly* belong to beryllium. As a rule these do not occur in the second order spectrum. A careful comparison with the spectra of elements likely to be associated with beryllium has shown that they do not belong to C, Si, Ca, Al, Fe, Mn, Mg, Sn, As, Ce.

JOHNS HOPKINS UNIVERSITY,
November 28, 1894.

ON SOME ATTEMPTS TO PHOTOGRAPH THE SOLAR CORONA WITHOUT AN ECLIPSE, MADE AT THE MOUNT ETNA OBSERVATORY.

By A. Riccò.

I.

With the Huggins Apparatus.[1]

My first attempts to photograph the solar corona without an eclipse were made at Catania with the Huggins apparatus on the day of the partial solar eclipse of 1893, April 16.[2] I obtained an image of a brilliant halo surrounding the solar disk; but since there was no interruption of the image such as the Moon should have caused, I was convinced that the image did not represent the solar corona.

The results of these first experiments could not, however, be regarded as conclusive, for during the eclipse the Sun was only from 6° to 25° above the horizon. I therefore continued the experiments in the months of May and June of the same year. The method was the same as that previously employed, except that the small blackened metallic disk, which served to intercept the direct image of the Sun formed by the speculum metal mirror, was no longer used. Dr. Huggins had previously recognized the fact that the disk serves no useful purpose. A change in the size of the disk or its complete removal produces no perceptible difference in the coronal image obtained.

The suppression of the occulting disk and the extreme brevity of the exposure rendered the use of a driving-clock wholly unnecessary. It sufficed to place the solar image in the center of the field immediately before the exposure. This was easily accomplished by making an image of the Sun, formed by a small hole pierced in a sheet of metal attached to the telescope,

[1] For a description of this apparatus see *Mem. Spettr. Ital.*, **13**, 108.

[2] *Mem. Spettr. Ital.*, **22**.

concentric with a circle drawn upon the screen which receives the image.

Previous to June 12 I obtained about twenty photographs in which the Sun is surrounded by a halo of nearly equal extent in all directions, but so shaded as to exhibit faintly marked rifts and streamers, which recall the appearance of the solar corona during eclipses. The extent of the corona varies from a quarter to half a degree in the various plates, according to the exposure and the development. But the streamers are not clearly marked in any of these photographs, and the rifts do not approach near enough to the solar limb to indicate with any certainty a structure like that of the solar corona.

At the following summer solstice I took the Huggins apparatus to the Observatory on Mount Etna (2950^{m}), where I made a second series of photographs on bromide plates (Lumière and Dringoli) and chloride plates (Dringoli), thirty-two in all. On most of the days of observation at this altitude, during this season, the sky was so pure that by occulting the Sun by the edge of the opening in the dome the blueness persisted up to the solar limb, and there was no trace of a brilliant atmospheric halo.

On this occasion, on account of a lack of snow or water at the Observatory, I had to postpone the development of the plates until my return to Catania, where it was carried out with the greatest care by Professor A. Mascari.

We were at first greatly surprised and delighted to see on six of the photographs great curved streamers bearing a remarkable resemblance to the solar corona at the time of its greatest development. But the results were so unexpectedly good that our suspicions were aroused. It was soon noticed that all of the streamers were concave toward the axis of rotation of the exposing shutter, which turns in front of the sensitive plate at a short distance from it. The arcs formed by the rays, although irregular and interlacing, were nearly concentric with the axis. Moreover, when we had determined the direction of the solar axis, we saw that the streamers (which always corresponded

closely in direction with the horizontal side of the plate) had their greatest extent before and after noon in various positions between the solar axis and equator. I finally concluded that the streamers might be produced by reflection of the very brilliant light of the solar image from the edge of the slit of the shutter. I recollected that I had noticed with surprise that the image falling on the slit gave rise to metallic reflections, although the slit-faces were blackened. It therefore seemed probable that the black had been rubbed away from some part of the edges by the frequent opening and closing of the slit, and that the brilliant reflections had fallen upon the sensitive plate.

On my return to the Etna Observatory in July and August I made a third series of photographs, taking care to blacken the edges of the slit before each exposure with lampblack mixed in alcohol. In order to determine whether the streamers had any connection with the shutter, I varied its inclination considerably for the different exposures. I also made some photographs with the slit-faces moved back so as to leave a circular opening $0^{m}.07$ in diameter. Still others were made with a sliding shutter operated by hand, which I made myself in the little workshop of the Observatory on Etna.

I obtained in this way twenty-two negatives, but on none of them were the streamers visible. The photographs made with a slit-width of less than $0^{m}.04$ in most cases showed the ordinary halo, the clearly marked streamers of which exhibited a polygonal or stellate form.

The negatives made with greater slit-widths or with the sliding shutter showed a reversed solar image, and the halo, which was often visible in spite of the density of the sky, was of the ordinary form.

In September I made a fourth series of fourteen photographs. By scraping the edges of the slit so as to expose the metal in several places, I obtained by reflection on the plates arcs somewhat more regular and more exactly concentric with the axis of the shutter and less dense near the image of the solar disk, but nevertheless closely resembling the streamers which I

obtained in the second series. There was thus no further doubt as to their purely instrumental origin.

On July 13, near the solstice, and again on August 14 of the present year (1894), I made a fifth and sixth series of photographs of the corona, and also some of the Moon for comparison. Part of the negatives were made on very sensitive Cramer plates, for which I am indebted to the kindness of Professor Hale. The greater part of the twenty-four photographs of the corona turned out very well, but in all cases the characteristic structure of the solar corona as seen during eclipses was absent.

The difference between the photographs of the corona made at Catania and those made on Mount Etna is simply a variation of intensity and extent, such as might result from differences in the exposure or development.

The photographs of the Moon, made on the less sensitive chloride and bromide Dringoli plates, showed nothing, even when the slit was wide open. With the more sensitive Cramer plates I obtained faint traces of the Moon in its last quarter an hour before sunrise, with slit-widths of $0^{m}.02$ and $0^{m}.04$. A negative of medium density was obtained with an exposure of 4^{s}, twenty minutes after sunrise.

If the corona was really obtained in the above experiments we may conclude that it has a stronger photographic effect than the Moon.

It follows from photographs made by the astronomers of the Lick Observatory[1] that, if we take as unity the actinic intensity of the light of a Carcel lamp shining upon a surface at a distance of one meter through a hole one millimeter in diameter, the intrinsic actinic intensities of the brightest parts of the corona were:

At the eclipse of August, 1886, - -	0.031
At the eclipse of January, 1889, - - -	0.079
At the eclipse of December, 1889, - -	0.029

Expressed in the same unit, the intrinsic actinic intensity of the full Moon is 1.66, and that of the sky 1° from the Sun is

[1] *Report of the Observations of the Total Solar Eclipse, December, 1889*, p. 14.

40.00. If we call the brightness of the corona 0.08, we have the ratio of the brightness of the corona : Moon : sky = 1 : 21 : 500.

Thus even when we take the corona at its brightest, and bear in mind the great difficulty of the measurements, we must admit that the light of the solar corona is always much fainter than that of the Moon, and far fainter than that reflected by the sky near the Sun. This conclusion is supported by the fact that at several eclipses the solar corona gave no sensible shadow, or at best a very faint one, while the Moon and the diffuse light of the sky gave a very strong one.

As in my photographs the photographic action of the halo was far greater than that of the Moon, we must conclude that it does not represent the true solar corona, but rather the diffuse light of our atmosphere around the Sun, which is considerably brighter than that of the Moon. This is true even at an altitude of nearly 3000 meters, although in this case the atmospheric illumination must be much less brilliant. This is easily evident to the eye; for under favorable conditions no bright halo is seen, although it is always visible to an observer at the sea-level. By photography, however, it has been found that the halo, which is sometimes invisible from the summit of Etna, is still quite bright enough to make a strong impression upon sensitive plates.

It is probable that part of the light of the halo results from the diffusion of direct sunlight from the imperfectly polished surface of the metallic mirror.

II.

WITH THE HALE APPARATUS.[1]

In 1893 Professor Hale, Director of the Kenwood Observatory of the University of Chicago, expressed to Professor Tacchini and me a desire to repeat upon Mount Etna the experiments in photographing the solar corona that he had been unable to carry to a successful conclusion on Pike's Peak, on account of the smoke from great fires in the surrounding forests. We assured Professor Hale that we would be very happy to

[1] For a full description of this apparatus see Hale, *A. and A.* **13**, 681.

place at his disposal everything at the Etna Observatory that could be of service to him, and we subsequently agreed to ascend Mount Etna together at the time of the next summer solstice. During our stay on the mountain he was to carry on his experiments with the spectroheliograph, while I continued mine with the Huggins apparatus.

We were so much retarded by the delay of Mr. Otto Toepfer, of Potsdam, in sending the spectroheliograph that we had to defer our expedition until July 7. Unfortunately there was just at this time a certain increase in the activity of the central crater, which was probably the prelude of the disastrous earthquakes on the eastern slope of the volcano which occurred on the 7th and 8th of August. The volumes of smoke rising from the great crater were carried by the prevailing northwest wind over the Observatory. There was also a serious difficulty in the fact that the sulphurous vapors mixed with the smoke tarnished the speculum metal mirror of the apparatus. A mirror, made by depositing a film of platinum and gold upon glass, was to have been sent from Berlin, but it was not finished on account of insuperable difficulties encountered in the process. As Professor Hale could not further prolong his stay, in the hope of enjoying atmospheric conditions comparable with those of my previous experience, he decided to leave the apparatus with me, in order that I might make use of the first favorable conditions to continue the experiments.

While I greatly regretted that Professor Hale had had no opportunity to try his method of photographing the corona, I was much pleased by his confidence in me, and anticipated with pleasure the experiments I hoped to make with the spectroheliograph on my next ascent of Mount Etna.

On July 14 the mirror was removed, and the entire spectroheliograph was carefully wrapped with cloth and paper. We then descended to Catania.

When I returned to the Etna Observatory on August 10, I found the spectroheliograph badly oxidized, in spite of its many coverings. Several days were required to clean it and get it in

order. As the mirror of gold and platinum had not arrived, I polished the speculum metal mirror as well as I could with absorbent cotton, wet with distilled water and alcohol. The entire mirror cell was then carefully painted with lampblack mixed in alcohol.

While awaiting perfect atmospheric conditions, I made a number of experiments in photographing the Sun's disk and the spectra of the Sun and sky. On August 24 the central crater emitted but little smoke, and the wind blowing from the east carried it far from the Observatory. The sky was of a beautiful blue in the zenith, and even near the limb of the Sun, though here the blue was lighter. I commenced at once to make photographs of the corona, which I developed immediately with the solutions left by Professor Hale. In the six negatives obtained between noon and 3 P. M. on this day, the shadow or silhouette of the disk which covers the fixed image of the Sun is surrounded by a clearly marked halo, which stands out well from the background of the sky, but is not very intense. This halo has a nearly uniform diameter, and the outer boundary is nearly circular and equally shaded in all directions. There is no visible trace of coronal structure.

The 25th of August was a cloudy day. On the 26th the sky was clear, but not so blue as on the 24th; a faint, whitish halo was seen surrounding the Sun when the direct light of the disk was occulted by the side of the opening in the dome. Nevertheless I made a second series of nine photographs of the corona, as I noticed that the purity of the sky gradually increased while I was at work. As arrangements had been made to leave the Observatory on this day, I did not have time to develop the plates immediately. They were developed two days later at Catania with the solutions used in our photographic work on the *Carte du Ciel*. The solutions were diluted at first, and strengthened during the development, in order to render it uniform and complete in spite of the great heat of the season. But even with this precaution the negatives were fogged a little, perhaps on account of the high temperature, or possibly because the devel-

oper employed was not so well suited for Schleussner plates as that used by Professor Hale.

In this series also the halo has a regular form. There is no sensible difference between the results of the two series, although they were made under different atmospheric conditions.

It is desirable to add some facts relative to the time of exposure of the negatives made with the spectroheliograph. In his preliminary experiments on Mount Etna Professor Hale found that the region of the K line in the spectrum of the Moon required an exposure of about 40 seconds with the Schleussner plates used. If in photographing the whole disk (11^{mm} in diameter) the second slit is $0^{mm}.2$ wide, an exposure of $\frac{11}{0.2} \times 40$ seconds $= 37$ minutes would be necessary; *i. e.*, the slit should move 11^{mm} in 37 minutes. I found the brightness of the sky to be so great that this exposure was far too long to give the corona. The photographs on which the halo was most distinctly visible on a faint background of sky had exposures of only from 3 to 9 minutes for the whole run of the spectroheliograph (about 51^{mm}). These correspond to exposures of from 40 to 120 seconds for the solar diameter. On the plates obtained with longer exposures the halo is lost in the dark background of the sky. The irregularities in the motion of the carriage are also more plainly evident, as at low speeds the motion is not so exactly controlled by the clepsydra.

Thus, even if we employ the spectroscopic method, we obtain halos much brighter than the Moon (20 to 60 times), while visual observations show the Moon and the corona to be of nearly equal brightness, and photometric observations indicate that the Moon is the brighter.

We thus reach the same conclusion as before. The halo obtained does not represent the true corona, but more probably a bright atmospheric illumination surrounding the Sun, although the photographs are made with a dark line, in which the light of the atmosphere is lacking (or more exactly, is relatively feeble). It is difficult to believe that this halo is caused simply by diffusion of the light of the Sun's disk in the lenses

and prisms of the apparatus, for when the first slit passes over the occulting screen it receives only the light from the regions outside of the photosphere. During the passage of the first slit there is certainly some diffusion throughout all, or nearly all, of its length. In fact, on four plates made with the slit moving rapidly across the image with the occulting screen removed, the sky is dark at the upper and lower limb of the Sun, while at those points where the slit in its motion becomes tangent to the limb, the sky is perfectly clear.

Finally, it may be that the halo is partly caused by the imperfect polish of the mirror, especially in the case of this apparatus, the mirror of which had been tarnished by the sulphurous fumes from the central crater of Etna. In order to learn what share this cause may have had in producing the halo, it would have been desirable to photograph a very brilliant globe or disk, to see whether a halo would have been formed. Unfortunately I had neither the time nor the means to make these experiments on Mount Etna.

OSSERVATORIO DI CATANIA,
September, 1894.

PLATE III

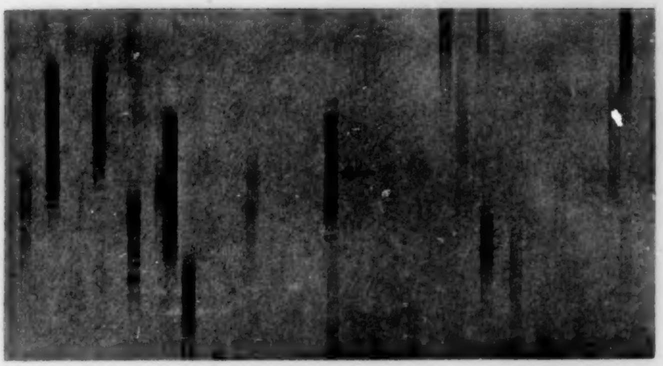

FIG. 1

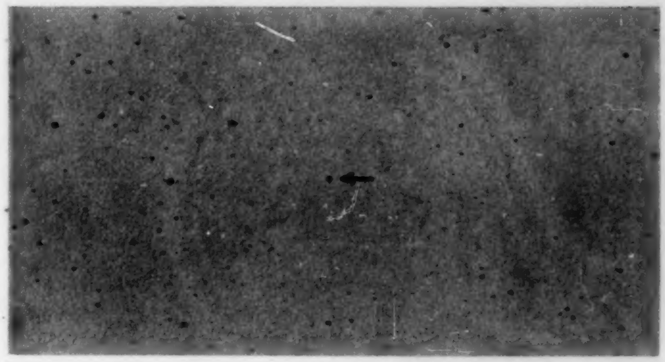

FIG. 2

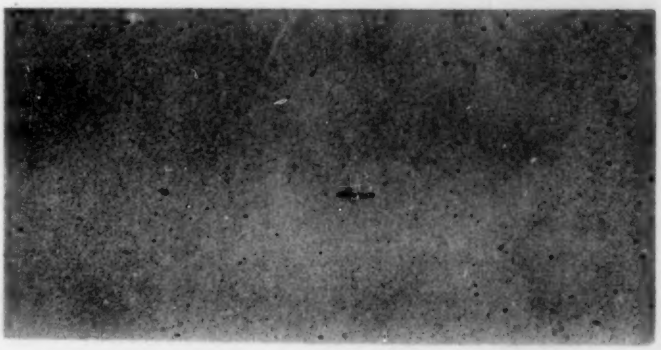

FIG. 3

PHOTOGRAPHS OF THE VARIABLE STAR *O. A.* 16,121 AND ITS SPECTRUM, TAKEN AT AREQUIPA, PERU

DISCOVERY OF VARIABLE STARS FROM THEIR PHOTOGRAPHIC SPECTRA.

By Edward C. Pickering.

An illustration of the method employed at the Harvard College Observatory, during the last five years, for discovering variable stars of long period from their photographic spectra is shown in Plate III. The spectra of a large part of this class of variables are of the third type, and when near maximum the hydrogen lines are bright. With perhaps a single exception, no star has yet been found having this class of spectrum which has not proved to be variable. The Henry Draper Memorial furnishes every year photographs of the spectra of many thousands of stars. From an examination of these spectra Mrs. Fleming has discovered thirty-four new variable stars, and has shown that sixty-five known variables have a similar spectrum. No star has been assumed to be variable from its spectrum, but in each case, on the examination of photographic charts of the region, taken on different days, marked changes in brightness have been found. The variation has also, in every case, been confirmed by the writer before announcement of variability has been made.

A photograph of the spectrum of *O. A.* 16,121, which is *Cord. DM.* $-30°$ 13,626, in the constellation Scorpius, and whose approximate position for 1900 is R. A. $= 16^h\ 50^m.3.$, Decl. $=$ $-30°\ 26'$, shows the hydrogen lines $H\gamma$ and $H\delta$ bright on plate B 10,104. This photograph was taken with the Bache Telescope at Arequipa, Peru, on August 6, 1893, exposure 60^m. It is represented in Plate III, Fig. 1, enlarged three times, so that the scale is $1' = 0^{cm}.1$ (nearly). The arrow indicates the spectrum of the variable, and also points to the hydrogen line $H\gamma$, which is bright, and therefore appears dark in the print, which is a negative. The line $H\delta$ is also seen to be bright and is about $0^{cm}.55$ below $H\gamma$. The bright star of the first type $2^{cm}.6$ to the left

of the variable is *Cord. DM.* $-30°$ 13,564 mag. 6.8. The principal lines shown in the spectrum of this star are $H\beta$, $H\gamma$, $H\delta$, $H\epsilon$, K, $H\zeta$, $H\eta$, etc.

Enlargements of charts of the same region, and on the same scale, are given in Figs. 2 and 3. They are made from plates B 6073 and B 3802, taken on May 28, 1891, and July 13, 1889, with exposures of 10^m each. In Fig. 2 the star is bright, while in Fig. 3 it is so faint as to be scarcely visible. Its maxima are represented by the formula J. D. 2,395,466 + 278 E. (See *A. N.* **135**, 161). Fifteen other photographs of the region show the variable in different degrees of brightness from the magnitude 7.3 to 11.6. The evidence regarding the other thirty-three variables mentioned above as discovered by this method is equally conclusive.

Harvard College Observatory,
Cambridge, Mass., Dec. 14, 1894.

PRELIMINARY TABLE OF SOLAR SPECTRUM WAVE-LENGTHS. I.

By HENRY A. ROWLAND.

THE following table of the lines of the solar spectrum has been in course of preparation at the Johns Hopkins University for many years in connection with an investigation of the spectra of the elements. The spectrum of every known element, except gallium (of which I have no specimen), has been photographed in connection with the solar spectrum, and some of these plates have been measured.

The whole solar spectrum has now been measured except the extreme ends, and the wave-lengths have been mostly reduced to my table of standards. Many of the lines, especially the stronger ones, have been identified with respect to the substance producing them, but this must be a labor of years. Hence I have determined to publish the work so far as I have now proceeded, expecting to add to it and correct it for a term of years, until I can publish a standard list of the lines of the solar spectrum with all the elements to which they belong.

The wave-length measurements have been made from my photographs of the solar spectrum, extending at present down to about wave-length 7200, and they will probably not be much changed in the future. The figures in the table refer to the wave-lengths in air at 20°C and 76^{cm} of mercury, as they are based upon the table of standards.

The intensities of the solar lines go from 1, a line just clearly visible on my map, up to 1000 for the H and K lines. Below 1 the lines in the order of faintness proceed from 0 to 0000, indicating lines more and more difficult to see.

The ordinary scale from 1 to 10 or from 1 to 6 is far too limited for the spectral lines, especially for the metallic spectra; 1 to 1000 is hardly great enough for the enormous difference in intensity. The small range, 1 to 10, ordinarily used gives an

entirely wrong idea to the worker in this subject, and many books with spectroscopic theories might have been saved by using a scale from 1 to 1000.

The expenses of this work have been partly borne by appropriations from time to time by the Bache fund of the National Academy of Sciences, the Rumford fund of the American Academy of Sciences, and the Bruce fund of Harvard College Observatory.

The measurement and calculation of wave-lengths have been made most carefully by Mr. L. E. Jewell.

My thanks are due to very many friends for assistance in procuring pure and rare elements, etc.

The symbols used are as follows: A line that is not clearly defined, or that is much weaker than it should be for a line of its breadth, is indicated by an N (such a line may generally be considered as composed of two or more lines too close together to be separated). Two lines close enough together to be considered double are indicated by a d, and a double whose components are very difficult to separate is indicated by d?; likewise three lines so close together as to be considered a triplet are indicated by a t.

Where several lines are connected by a large brace there is generally shading extending from the center of some strong line to other lines at the extremities of the braces. This is the case with the stronger lines of iron and some other elements.

In the column devoted to the identification of the solar lines an interrogation mark indicates that the identification of the solar line with the element given is uncertain. Where two or more elements are given, the solar line is compound. The order in which they are given indicates the portion of the line due to each element, as follows: C-Fe-Cr. However, it is not always possible to correctly assign the exact positions, and consequently there are probably many errors in the positions assigned. Where the solar line is too strong to be due entirely to the element with which it is identified, it is represented thus:

—Fe, and indicates that the iron line is coincident with the red side of the solar line, the origin of the rest of the line being unknown. If, as far as can be determined from the plates, two metallic lines coincide exactly with the same portion of a solar line, this is shown by using a comma instead of a dash. Thus: Fe, Cr. In some cases when a double line is particularly difficult to separate, measurements are given on the two components and also on the line unresolved. This last measurement is placed in parentheses between the other two measurements. Thus

$$\begin{array}{cc} \text{W.-L.} & \text{INTENSITY.} \\ \left.\begin{array}{c} 3738.454 \\ (3738.466) \\ 3738.505 \end{array}\right\} & \left.\begin{array}{c} 3 \\ 6 \\ 2 \end{array}\right\} \text{d} \end{array}$$

means that there is a line at *w.-l.* 3738.466 with the intensity 6; and that with good definition this line may be resolved into two components having the intensities 3 and 2 and the given wave-lengths.

JOHNS HOPKINS UNIVERSITY,
Baltimore, Dec., 1894.

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3722.071	Fe	3	3729.096	Ni	1 d?
3722.174		2	3729.214	C ?	000 N
3722.280		00	3729.481		0
3722.377		1	3729.666		00
3722.518		0 N	3729.865		000
3722.639	Ni	3	3729.952	Ti	3
(3722.692) s		10	3730.154		00
3722.729	Ti-Fe	6	3730.283		000
3722.899		0	3730.450		1
3722.987		000	3730.5[illegible]4	Fe	3
3723.319		000	3730.625	Co	2
3723.425		00	3730.732		00
3723.533		00	3730.898	Ni	1
3723.651		00	3730.950	Cr	1
3723.750		1	3731.093	Fe	3
3723.827		00	3731.301		00
3723.985		0	3731.403	Co-Zr	0
3724.053		00	3731.523	Fe	3
3724.233	Ti	1	3731.763		00
3724.399		000	3731.869		00
3724.526	Fe	6	3731.956		000
3724.716	Ti	1	3732.072	Mn	0
3724.884		00	3732.177	Cr	2
3724.970	Ni	1	3732.284		00
3725.090		0 N d ?	3732.356		000
3725.300	Ti	1	3732.545 s	Ti-Fe-Co	6
3725.447		0	3732.776	C-	0 N d?
3725.638		3	3732.894		2
3725.806		00	3733.028		000
3725.978		000	3733.128		000
3726.164		0	3733.222		000
3726.206		00	3733.338		1
3726.558		000 N d?	3733.469 s	Fe-	7 d?
3726.806	Co	0	3733.635	Co	1 N
3726.983		00	3733.798		000
3727.061	Fe-Mn	4 d?	3733.910		00
3727.167		0	3733.984		000
3727.244	Fe	3	3734.160		00 N
3727.488		1	3734.278	Co	1
3727.590		0	3734.428		000
3727.672		1	3734.608		00 N
3727.778 s	Fe	4 d	3734.679		1
3727.826		1	3734.807		0 N
3727.965		2	3735.014 s	Fe	40
3728.183		1	3735.135		00
3728.278		00	3735.261		0 N
3728.474		0 N	3735.387		000
3728.544		00	3735.485	Fe	4
3728.813	Ti-Fe	2	3735.587		000
3729.004	Mn	00	3735.694		000

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3735.843		0 N d?	3742.286		1
3736.041	Co	1	3742.418	C?	00
3736.107		0	3742.707		2
3736.187		00	3742.763	Fe	3
3736.321		000	3743.086	Cr	1
3736.434		000	3743.269		00
3736.619		00	3743.358		0
3736.734		000	3743.508 s	Fe	6
3736.854		000	3743.626	Ti	2
3736.958 s	Ni	3	3743.726	Cr	1
3737.059 s	Ca–Mn	5	3743.921		1
3737.174		00	3744.029	Cr	2
3737.281 s	Fe	30	3744.138		000
3737.441		1 N d?	3744.251	Fe	4
3737.718		00 N	3744.303		000
3737.900		00	3744.513		000
3738.026		00	3744.634	Cr	0
3738.128		000	3744.697	Ni	1
3738 211		00	3744.898		000
3738.281		000	3744.959		000
3738.454	Fe	3	3745.190		000
(3738.466)		6 d	3745.279		000
3738.505		2	3745.371		00
3738.652		1	3745.491	Co	2
3738.773		000	3745.617	Ti	1
3738.900		00	3745.717 s	Fe	8
3738.946		000	3745.751	Ni	1
3739.140		00	3746.058 s	Fe	6
3739.260	Fe	2	3746.191	Ni	0
3739.370	Ni	3	3746.287		000
3739.467	Fe	1	3746.387		1
3739.674	Fe	3	3746.511		00
3739.926	Ni	1	3746.618	Fe	2
3740.085	Bi?	000	3746.717	Mn	1
3740.205	Fe	2	3746.864		00
3740.386	Fe	3	3747.065 s	Fe	3
3740.477		0	3747.147		2
3740.605		0000	3747.369		0
3740.672		0000	3747.492		00
3740.952		0000	3747.694		1
3741.025		0000	3747.864		000
3741.205	Ti	4	3747.965		00
3741.339		00	3748.144	Ti	1
3741.453		0	3748.232	Ti?	0 N
3741.619		1	3748.408 s	Fe	10
3741.701		0	3748.549		0
3741.791	Ti	4	3748.650		1
3741.973	C	000	3748.749		0
3742.043	C-	00	3748.821	Cr	1
3742.219	Fe	1	3748.943		000

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3749.049	Fe	0	3755.863		00
3749.110	Cr	2	3755.964		00
3749.195	Ni	1	3756.080		000
3749.388		0 N	3756.213 s	Fe	3
3749.509		00 N	3756.405	C?	00
3749.631 s	Fe	20	3756.480	C?	00
3749.764		0	3756.705	Mn	000
3749.884		000	3756.791	C-	00
3749.994	C?	00	3757.081	Fe	4
3750.082	Co	0	3757.212		000
3750.283	C?	000 } N	3757.304	Cr	1
3750.349	C?	0000 }	3757.444	C?	0
3750.448		1	3757.508	C?	00
3750.648		000 N	3757.597	Fe	2
3750.823		1	3757.824	Cr-Ti	4
3750.916	Mn	00	3757.950		00 N
3751.015		2	3758.099		0
3751.136		000	3758.173		0
3751.234	Fe	1	3758.269		00
3751.367		0 N	3758.375 s	Fe	15
3751.592		00 N	3758.456		0
3751.735	Co	1	3758.577		0
3751.802	Zr	00	3758.736		0 N
3751.967	Fe	1	3758.863		00 N
3752.055		000	3758.967		00 N
3752.334	C	000	3759.096		0 N
3752.408	C	000	3759.215	Zr	1
3752.556	Fe	3	3759.297	La-Fe	2
3752.648		000	3759.447	Ti	12d?
3752.830		00	3759.613		0
3753.003	Ti	4	3759.725		1
3753.134		1	3759.829		00
3753.282	Fe	2	3759.940		00
3753.482		1	3760.032	C?	000
3753.667		000	3760.196	Fe	5
3753.732	Fe-Ti	6	3760.364		1
3753.893		00	3760.531	C?	00 N
3754.009		000	3760.679	Fe	4
3754.265		000	3760.844		00
3754.367	C	00	3761.070	C	00
3754.481	Co-C	00 N	3761.206		1
3754.647 } s		3 }	3761.464	Ti	7
3754.719 }		1 }	3761.568	Fe	2
3754.866		000	3761.695	C	000
3755.015		00 N	3761.830	C-	1 N
3755.147		000	3762.012	Ti	3
3755.275		0	3762.349		2
3755.421		00	3762.448	C-	1
3755.593	Co	1 N	3762.495	C-	1
3755.714		00	3762.616		000

3757.6
3758.
3758.6
37

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3762.758		1	3770.132 s	Fe	4
3762.895		000	3770.308	C	00
3763.008	C	00 N	3770.446	C-Fe	2
3763.147		2	3770.553		2
3763.313		000 N	3770.671		000
3763.426		0000	3770.739		[1] 1
3763.514		000	3770.859		0 N
3763.614		00	3770.992		000
3763.709		1	3771.116		2
3763.945 s	Fe	10	3771.258		00
3764.117		0 N	3771.418	C	000
3764.251		1	3771.471	C	00
3764.359		1	3771.636		1
3764.422	C	00	3771.798	Ti-C	2
3764.522	C-	00 N	3771.956	C	00
3764.727	C	00	3772.111		000
3764.787	C	00	3772.250	-C	0 N
3764.986	-C	00	3772.330	C	00
3765.059	C	000	3772.524		000
3765.194		00	3772.673	Ni	2
3765.441		0	3772.730		1
3765.689	Fe	6	3772.918		000
3765.847	Fe	1	3773.070	C	0 N d?
3766.234	Fe	2	3773.345	C	00 N
3766.377	-C	00	3773.503		1
3766.460	C	000 N	3773.609	C	00
3766.594	C	00	3773.695	C	00
3766.801	Fe	3	3773.803	Fe	3
3766.955	Fe	1	3774.029		00
3767.105		1	3774.170	C	00
3767.218		0	3774.247	C	00
3767.341 s	Fe-	8	3774.357		0000
3767.493		1 N	3774.473 s	Y	3
3767.574		0	3774.650	C	000
3767.682	C	00	3774.791	Ti-C	1
3767.787	Mn	0	3774.971	Fe	4
3767.842		00	3775.137		000
3768.034		00	3775.342	C	00
3768.173	Fe	3	3775.431	C	00
3768.232	C	000	3775.562		000
3768.385	C-Cr-Fe-C	2	3775.717	Ni	7
3768.544		0	3775.849	Tl	000
3768.799		0	3775.997		1
3768.871	Cr	1	3776.090	C	00
3769.157		0 N	3776.198	Ti	2
3769.454		00 N	3776.337	C	0 N
3769.603		3	3776.473		000 N
3769.792		000	3776.600	Fe	3
3769.861		00	3776.698	Mn	1
3769.752	C	00	3776.830		000

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Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3776.977		000 N	3783.224		000
3777.057		000	3783.328		00
3777.210	Fe-C	2	3783.483		2
3777.370		000	3783.601	C	00
3777.470		1	3783.674 s	Ni	6
3777.593	Fe	3	3783.954	C	00
3777.701	C	000	3784.035	C	00
3777.809	C	00	3784.391		0
3777.897	C	00	3784.511	C	00
3777.982	C	0	3784.641	C-	0
3778.075	C	0	3784.814		000 N
3778.203	Ni	2	3784.965		000 N
3778.301		0	3785.152		000
3778.463	Fe	3	3785.223		000
3778.652	Fe	2	3785.373		0
3778.841	V-Fe-C	3	3785.457	C	0
3778.939	C	1	3785.539	C	0
3779.049		000	3785.641	C	00
3779.165		00	3785.719	C	00
3779.236		0000	3785.846	Fe	1
3779.343	C-	1	3785.929		1
3779.451	C	00	3786.092	Fe	3
3779.569	Fe	4	3786.181	Ti	1
3779.657	Fe	2	3786.314	Fe	4 d?
3779.713		0	3786.468		1
3779.871	C	0	3786.587		1
3779.989	C	0	3786.661		0
3780.083		000	3786.820	Fe	5
3780.223	C	000	3786.983		00
3780.363	C	000	3787.104		000
3780.564	C	00	3787.240	Cr	000
3780.654	C	00	3787.304	Fe-C	1
3780.842 s		3	3787.379	C	0
3780.994	C	00	3787.558		000
3781.128		000 N d?	3787.620		000
3781.330 s	Fe	3	3787.713		00
3781.460		00	3787.852		00 N
3781.655		00	3787.922		0
3781.754	C-	1	3788.046 s	Fe	9
3781.818	C	00	3788.189		00
3781.935		000	3788.283		00
3782.078	Fe	2	3788.353		000
3782.258	Ti-Fe	1	3788 574	C-	0
3782.354	C	0	3788.666	C	00
3782.455	C	00	3788.839		2
3782.592	Fe	2	3788.953	C	0
3782.755	Fe	1	3788.999	Cr	1
3782.868		000	3789.110	C	0
3782.987		000	3789.186	C	0
3783.135	C	000	3789.319	Fe	3

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3789.439		0	3795.441	C-	0
3789.553	Fe	1 N	3795.513	C	00
3789.637		0	3795.593		0
3789.719	Fe	1	3795.680	Fe	1
3789.867		0	3795.880	C	00
3789.991		1	3795.952	C	00
3790.059		000	3796.040		0
3790.238	Fe	5	3796.154		0
3790.362	Mn	2 N	3796.247	C	0
3790.471	V?	00	3796.329	C	0
3790.585	C	0	3796.449	C?	00
3790.629	Cr-C	1	3796.531		0
3790.793		1	3796.635		0
3790.910	Fe-C	2	3796.943		1
3790.972	La-Ca	1	3797.032	-C	2
3791.132		000	3797.115	C	00
3791.246	C	0	3797.205	C	000
3791.332	C	000	3797.283	Cr-C	0
3791.517	Cr-C	1	3797.387	C	00
3791.645	Fe-C	2	3797.597		00
3791.885		1	3797.659	Fe	5
3792.041		000 N	3797.860	Cr	1
3792.216	C	00	3797.991	C	0
3792.294	Fe-Cr-C	3	3798.093	Fe-C	2
3792.482	Ni	1	3798.224		[1] 00
3792.702	C	0	3798.306		000
3792.788	C	0	3798.396	Mo	0
3792.824		2	3798.486		000
3792.969	Fe-C	2	3798.655 s	Fe	6
3793.069	C	000	3798.791	C	0
3793.128		000	3798.912		000
3793.262		000 N	3799.047		0
3793.429	Cr	1	3799.159		000
3793.495		1	3799.272	C	00
3793.622	Fe	2	3799.386	Mn-C	1 N d?
3793.745	Ni	4	3799.486		00
3793.846	C	000	3799.586		0
3793.921	C	00	3799.693 s	Fe	7
3794.016 s	Fe	2	3799.818	C	0
3794.107		000	3799.934	V	1
3794.225		000	3800.046		0
3794.313		000	3800.174	C	0
3794.485	Fe-C	4	3800.256	C	0
3794.555	C	0	3800.457	C?	0 N
3794.679		0	3800.683	Mn	1
3794.753	Cr	0	3800.766		0
3794.909	La	1	3800.877		00
3795.032	V	1 N	3800.992		0
3795.147 s	Fe	8	3801.163	Sn?	000
3795.292		1 N	3801.251		0

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Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3801.331		0	3807.293	Ni	6
3801.439	C	0	3807.425		00
3801.511	C	1	3807.539		00
3801.679	-C	0 N d?	3807.681	Fe	6
3801.820	Fe	3	3807.831	C	00
3801.953	Fe	2	3807.914		000
3802.051	Mn	00	3808.076	Cr-C	1
3802.133		2	3808.223	Co	0
3802.271		00	3808.274	Ti-Ni-C	1
3802.424	Fe	2	3808.423	Fe	1
3802.614		00	3808.659	V	0
3802.725		000	3808.770		000
3802.870	C	0	3808.873	Fe	3
3802.952	C	0	3809.189	C-	1
3803.097		0	3809.305	C	0
3803.141	C	0	3809.552	C	00
3803.228	C	1	3809.633	Mn-C	00
3803.317	C	00	3809.724	Mn	4
3803.398		1	3809.834	Mn-C	0
3803.618	V?	0	3809.894	C	0
3803.711		00	3810.061	C	00
3803.816		00	3810.174		00 d?
3803.910		000	3810.434		00 d?
3804.044	C	00	3810.681	C	0
3804.151 s	Fe	3	3810.761	C	0
3804.237	C	00	3810.854	C	000
3804.317	C	00	3810.901	Fe-C	3
3804.424		0	3811.047		0
3804.484		000	3811.181	-C	1
3804.621		00 N	3811.317		000
3804.752	-C	1	3811.443	-C	1
3804.836	C	1	3811.525	C	0
3804.934	Fe-Cr-C	2	3811.667		000 N
3805.070		00	3811.787		000 N
3805.256	C	00	3811.945	Fe	2
3805.337	C	00	3812.033		2
3805.486 s	Fe	6	3812.126	C	0
3805.589	C	00	3812.205	C	0
3805.669	C	00	3812.340	C	000
3805.884		0 N	3812.389		00
3805.989		00	3812.589		000
3806.103		000	3812.733		000
3806.255	C	0	3812.813		000
3806.357	Fe-C	2	3813.000		0 N
3806.511	C	0	3813.100	Fe	5
3806.586	C	0	3813.219	Fe	2
3806.711		00	3813.405	C	0
3806.865	Mn-Fe	8 d?	3813.537	C	2
3807.012	V-Mn-C	0	3813.637	V-C	0
3807.148		000	3813.781	Fe	2

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3814.034	Fe	2 d	3819.938	C?	00
3814.070		1	3820.042		0 d
3814.154		0	3820.102	C	0
3814.264		0	3820.197		00 N
3814.386		000	3820.337		0 N
3814.500	C	00	3820.444		0 N
3814.671	Fe-C	4	3820.586 s	Fe-C	25
(3814.698)		8 d	3820.702	C-	1
3814.738	-C	3	3820.797	C?	0
3814.796	C-	1	3820.889	C	1
3815.038	C	0	3820.950	C	0
3815.222		00 N	3821.017		0
3815.352		00 N	3821.130		00
3815.462		1	3821.328 s	Fe	4
3815.572	Cr	1	3821.636		00
3815.759		0 N	3821.725		00
3815.987 s	Fe	15	3821.866	C	1 N
3816.252	C?	0 N	3821.981	Fe	4
3816.332	C?	0	3822.077	Ti	0
3816.490	Fe-Co	3	3822.157	V	0
3816.610	Co	1	3822.250		000
3816.779	C	00 N	3822.406	C	0
3816.887	Mn	1	3822.470	C	0
3816.998		0000	3822.557		000
3817.059		1	3822.785		00
3817.114		000	3822.924		000
3817.198	C	00	3822.996	V	1 d?
3817.290	C	000	3823.092	C?	00
3817.523	Co-Ti-C	0	3823.163	C	0
3817.602		00	3823.228	C	0
3817.725		00	3823.352		0
3817.786	Fe-C	3	3823.493		00 N
3817.877	C	0	3823.653 s	Mn-Cr	4
3817.985	Ti-Cr-C	0	3823.893	C	0
3818.089		000	3823.953	C	0
3818.225		000	3824.028	Mn	1
3818.337	C	00	3824.139	C?	00
3818.378	V-C	1	3824.216	Fe	1
3818.487		1	3824.373		000
3818.613	Cr	0	3824.441		2
3818.759	C	1	3824.591	Fe	6
3818.891	C?	000	3824.711		1
3819.031		000	3824.780		000
3819.197	C	1 N d?	3824.887		00
3819.346	C	1	3824.936		0
3819.412	C	1	3825.057		1
3819.521	C	00	3825.183		000
3819.637		2	3825.256		00
3819.715	Cr	0	3825.373	C	0
3819.829	C-	1 N d?	3825.448	C	0

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3825.543		2	3831.334		00 N d?
3825.736		1 N	3831.517	-C	00 N
3825.820	C?	1 N	3831.657		000
3826.027 s	Fe	20	3831.837	Ni	6
3826.163		0 N	3832.025	C	0
3826.229		0	3832.171		0
3826.343	C?	0	3832.303		0
3826.449	C?	0	3832.450 s	Mg	15
3826.555		1	3832.647	C	0
3826.636		000	3832.790		0
3826.761		1 N	3832.890		000
3826.843	C	0	3833.026		3 N
3826.905	C	00	3833.156	C	0
3826.988	-C	2	3833.221	C-	1
3827.096	C	0	3833.348		0
3827.220		0	3833.458	Fe	4
3827.348		00	3833.628		000 N
3827.435		1	3833.744	C	0
3827.519	C	0	3833.836		0
3827.622		000	3833.916	C	0
3827.714		2	3834.006	Mn-C	3
3827.828		1 N	3834.096		000
3827.980 s	Fe	8	3834.189		0 N
3828.155		1 N	3834.364	Fe	10
3828.296	Ti-C	1	3834.506	Mn	4
3828.360	C	0	3834.614		0
3828.539	C	00	3834.609	C	0
3828.646	V	0	3834.762	C	000
3828.702		0	3834.869		0
3828.795		000	3834.978		00 N
3828.971		00	3835.022		000
3829.108		000	3835.176		00 N
3829.195		000	3835.298	C	0
3829.284	Fe	1	3835.342	C	0
3829.386		00	3835.509	C	[1] 1 d?
3829.501 s	Mg	10	3835.689	C	0 N d?
3829.617	Ti-C	2	3835.862	-C	000 d
3829.728	Fe-C	0	3836.116		000
3829.822	Ti-C	1	3836.229 s		2
3829.909		1	3836.337	C	000
3830.037		000	3836.476	Fe	3
3830.211		0	3836.639 s	C	1 d
3830.447		000	3836.689 s	C	1 d
3830.513		0	3836.808		000
3830.627		0	3836.905		1
3830.745	C	0	3837.059		1
3830.801	C	0	3837.277		2
3830.896	Fe	2	3837.404		000
3831.002	Fe	2	3837.559	C	0 N d?
3831.174	C-	3 d	3837.768	C	1 d?

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Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3837.961	C	0	3844.714		0
3838.035	C	0	3844.861		00 N
3838.188		0 N	3845.023		0
3838.345		1 N	3845.149	C	1
3838.435 s	Mg-C	25	3845.310	Fe	3
3838.675		0 N	3845.358		1
3838.888	C	1 N d?	3845.461	C	000
3839.135		0	3845.606	Co-C	8 d?
3839.275	C	1	3845.729		000
3839.405	Fe	3	3845.837		1
3839.582		0	3845.949	C	00 N d?
3839.762	Fe	2	3846.131	C	2
3839.922	Mn-C	2	3846.421		1
3839.987	C	0	3846.554	Fe	2
3840.067		00	3846.666		00
3840.239	C?	0	3846.777	C	1
3840.340	Mn	0	3846.814	C	1
3840.440	V	0 N	3846.943	Fe	5
3840.580 s	Fe-C	8	3847.087	C	1
3840.720		0 N	3847.121	C	00
3840.893	V	1 N	3847.261		000 N
3841.034	C	0 N d?	3847.394	C	00 N
3841.195	Fe-Mn	10	3847.477	V	00
3841.327		0	3847.567		00
3841.420	Cr	1	3847.654		000
3841.486		00	3847.827		000
3841.595	Co	0	3847.961	C	1
3841.720		000 N	3848.006	C	1
3841.862	C	2 d?	3848.100	C	0
3841.959	C	0	3848.186		00
3842.082	C	0	3848.249		00
3842.191	Co	3	3848.329	C	00
3842.354	-C?	0 d?	3848.432		2
3842.500		000	3848.580		000
3842.587	C	00	3848.667		00
3842.779	C	0	3848.745		00
3842.904		000	3848.840		00
3843.038		1	3848.979	C	1 N
3843.127	C	3	3849.140	La-C	3 d?
3843.195	Fe-C	2	3849 248		000
3843.404 s	Fe	4	3849.400		000
3843.600	C	0 N	3849.501	C?	1 N
3843.762		000	3849.675		1
3843.854		2 N	3849.886	C	0 N
3843.962		000	3850.013		0
3844.135	Mn-C	2	3850.118	Fe	10
3844.167		0000	3850.300	C	1 N d?
3844.267		000	3850.440		00
3844.378	C	4 d?	3850.536		00
3844.587	V	0	3850.626		0

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3850.700		00	3856.674		0
3850.781	C?	0	3856.802	C?	2 N
3850.962	Fe	4	3856.955		000
3851.098	Co?	0	3857.063	C?	0
3851.220		000	3857.135	C?	000
3851.306		00	3857.215	C?	000
3851.427	C	2 N d?	3857.288	C?-	1
3851.580		000	3857.473	C	0
3851.672	C	0	3857.580	C	00
3851.733	C	00	3857.805	C?	6 d?
3851.815	C	00	3857.955	C?	0
3851.895		00	3858.033	C?	1
3851.993	Co-C	00	3858.146	C?	00
3852.132		000	3858.262		1 N
3852.245	C	00	3858.442	Ni	7
3852.347	C-	1	3858.606	C	0
3852.541	C?	2 N d?	3858.642	C	000
3852.714	Fe	4	3858.722	C	0
3852.845	C	00	3858.822	C	2 N
3852.899	C	000	3859.000		1 N
3853.045	C	00	3859.052	C?	1
3853.184		00	3859.128	C	00
3853.333	-C	1 d?	3859.246	C?	00
3853.477	-C	0 N	3859.355	Fe	3
3853.620	C	2 d?	3859.415	C	000
3853.805	C	00	3859.535		000
3853.872	C-	0	3859.568	C?	0
3853.967	C	000	3859.788	C-Ni	0
3854.040	C	00	3859.876	C	00
3854.191	C	0	3860.055 s	Fe-C	20
3854.343		0	3860.227	C-	0 N
3854.401		00	3860.354	C?	0 N
3854.507		2	3860.427		00
3854.707	C	2 N d?	3860.566	C	0
3854.808	C	0	3860.630	C	0
3854.869	C	0	3860.767	C-Ni	3 N
3854.989	C	1	3860.863	C	000
3855.088	C	00	3860.963	C	0
3855.259	C?	00	3861.067	C	00
3855.450	V	2	3861.158	C-	0
3855.547		1	3861.299	C-Co-C	4 N d?
3855.721	Fe-C	1	3861.479	C-Fe	3
(3855.749)		5 d	3861.592	C	00
3855.766	C	3	3861.681	C	1
3855.989	V	4	3861.734	C	2
3856.107		00	3861.847	C	2 N
3856.161		1	3861.978	C	1 N
3856.282		000	3862.114	C-	1 N
3856.367		0	3862.248		000
3856.524 s	Fe	8	3862.361		000

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3862.458	C	00	3867.996	C?	000
3862.541	C	000	3868.060	-C	2
3862.627	C?-	2	3868.171	C	00
3862.727		1	3868.261	C	0
3862.827	C	000	3868.372	-C	0
3862.897	C	00	3868.451		000
3862.962		0	3868.539	C	1
3863.041	C	00	3868.625	C	00
3863.113	C	00	3868.700	C	0
3863.201		1	3868.785	C	00
3863 341		000 N	3868.873	C	1
3863.533	C	3 N	3868.941	C	0
3863.655	C	00	3869.179	C	0
3863.734	C	00	3869.305	C-	1
3863.835	C-	1	3869.444	C	0 N d?
3863.888	Fe	3	3869.533	C-	1
3864.006		0	3869.692	Fe-C	3
3864.113	C	0	3869.745	C	1
3864.246	Mo-C	1	3869.805	C	1
3864.438 s	C	3	3869.960	C	00
3864.626	C	1	3870.053	C-Co	1 N
3864.720	C	00	3870.204	C	0
3864.802	C	00	3870.289	C-	1 N
3865.005	V	3 N d?	3870.405	C?	00
3865.134	C	0	3870.493	C?	0
3865.213	C	000	3870.615	C-	1
3865.282	C?	3	3870.685	C	0 N
3865.454	C	0	3870.797	C	0 d
3865.554	C	0	3870.848	C	00
3865.674	Fe-C	7	3870.932	C	0
3865.793	C	0	3871.018	C	1
3866.046	C?	000	3871.145	C	0
3866.122	C?	3 N d?	3871.259	C	0
3866.238	C	00	3871.356	C-	1
3866.306	C	00	3871.527 s	C	[1] 2 d?
3866.380	C	00	3871.693	C	0
3866.526	C	00	3871.785		00
3866.577	C-	1	3871.963	Fe	2
3866.692	C	0	3872.035		0
3866.854		0	3872.202	C-	1 N
3866.960	C-	2	3872.312	C	0
3867.118	C	0	3872.405	C-	1 N
3867.205	C	0	3872.639	Fe	6
3867.356	Fe-C	3	3872.859	C	1 N d?
3867.449	C	0	3872.969		00
3867.520	C	0	3873.065	-C	2
3867.573		0	3873.224	Co	2
3867.758	C-V	1	3873.267		2
3867.791	C	0	3873.333		00
3867.906	C-	1	3873.427		0

[1] Beginning of the second head of "Cyanogen band."

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3873.504	C-	0	3879.458	C	0
3873.636	C	0	3879.578	C	000
3873.706	C-	1	3879.716	C	1
3873.903	Fe	4	3879.796	C	0
3874.091	Co-C	4	3879.851	C	0
3874.191		1	3879.986	C	00
3874.258	C	00	3880.105	C	1
3874.328	C-	0	3880.175	C	0
3874.491		000 N d?	3880.235	C	0
3874.651		2	3880.328	-C	0
3874.708	-C	0	3880.393		0000
3874.861	C	1	3880.465	C	1
3874.911	C-	2	3880.532	C	2
3875.220 s	V	2	3880.596	C	1
3875.425	Ti-C	2 N d?	3880.684	C	000
3875.513	C	1	3880.815	C	1
3875.681		00 N	3880.931	C	1
3875.793		00	3881.038	C	000
3875.920	C-	2	3881.140	C	1
3876.019	C	0	3881.254	C	1
3876.083	C	0	3881.346	C	0
3876.194	Fe	5	3881.445	C	2
3876.448	C	0	3881.543	C	1
3876.556	C	0	3881.628	C	000
3876.622	C	0	3881.729	C	1
3876.702		000	3881.825	C	1
3876.815	Fe	1	3882.011	C-Co	2
3876.981	Co-C	4	3882.118	C-	1
3877.121	C	4 N d?	3882.224	C	1
3877.232		00	3882.309	C	1
3877.337		1 N	3882.439	C-	2
3877.481	C	1	3882.530	C	1
3877.587	C	0	3882.650	C	1
3877.646	C	0	3882.733	C	1
3877.745		00	3882.828	C	1
3877.845		000	3882.893	C	0
3877.972	C	0	3882.986	C	1
3878.072	C	00	3883.033	C	1
3878.152	Fe-C	8	3883.133	C	2
3878.334		1	3883.253	C	1
3878.438	C-	2	3883.339	C	0
3878.549	C	0 d?	3883.426 s	C-	2
3878.720	Fe	7 N d?	3883.533	C	[1] 1 N
3878.816	Co-Fe	2	3883.568 s		[2]
3878.884	C-Fe	2	3883.690		000
3878.975	C	0	3883.778 s	Cr	0
3879.037	C	0	3884.236		000
3879.178	C?	00 N	3884.361		00
3879.331	C	1	3884.431		0
3879.394	C	0	3884.518	Fe	2

[1] First line in first head of "Cyanogen band." This line and the preceding one were measured together as a single line in the series of measurements upon which were based Rowland's Table of Standards.

[2] Edge of "Cyanogen band."

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3884.579		00	3891.918		0
3884.748	Ca	1	3892.069	Fe	4
3884.812	Fe	1	3892.153		000
3884·986		0	3892.373		00
3885.101		00	3892.450		0
3885.207		00	3892.590		00
3885.290	Fe	2	3892.698	Mn	2
3885.364	Fe-Cr	2	3892.873		000
3885.426	Co	00	3893.033	V-Fe	2
3885.657	Fe	4	3893.124		1
3885.797		00	3893.213		1
3885.895		1	3893.352		000
3886.005		0	3893.451		2
3886.073		0	3893.542	Fe	4
3886.205		00 N	3893.600		0
3886.295		00 N d?	3893.743		000
3886.434 s	Fe	15	3893.932		000
3886.568	V	0	3894.057	Fe	2
3886.942	Cr	3	3894.165	Cr	3
3887.080		00	(3894.211)		8 d
3887.196	Fe	7	3894.241	Co	5
3887.512		000 N	3894.355		0000
3887.666		000 N	3894.511		0000
3887.870		000 N	3894.630		1 N
3888.030		00	3894.768		00
3888.179	Ti	0	3894.850	Mn	0
3888.560		2	3895.119	Co	3
3888.671	Fe	5	3895 224	Ce	1
3888.863		00 N	3895.304		00
3888.971	Fe-Mn	2	3895.377	Ti	2
3889.077		[1] 0	3895.470		1
3889.245		1	3895.583	Mn	3
3889.374		1 N d?	3895.719		0
3889.498	Mn	1 d?	3895.803	Fe	7
3889.675		00 N	3895.931		0
3889.810	Ni	2	3896.279	V?	0
3889.986		0	3896.385	Mn	00
3890.069		1	3896,500		00
3890.222		000	3896.608		1
3890.336	V	1 N	3896.671		0
3890 450		000	3896.759	Zr	0
3890.538	Fe-Zr	2	3896.917	Ce	0 N
3890.707		1 N	3897.119		000
3890.861		00	3897.210		000
3890.986	Fe	3	3897.336		000
3891.084		00	3897.482		000
3891.339		1 N	3897.596 s	Fe	2
3891.521		0	3897.785	Zr	0
3891.649		1 N	3897.915		0
3891.820		000	3898.032	Fe	3

[1] Haze, which is perhaps due to Hydrogen.

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3898.151	V	5	3905.017		1
3898.231	Fe	2	3905.146		1
3898.414		00	3905.326		2
3898.531	Mn	2	3905.497		1 N
3898.645	Ti	0	3905.660 s	Si	12
3898.911		000 N	3905.816		2 N
3899.015		0000	3905.906		1 N
3899.171	Fe	3	3906.044		3
3899.277		2	3906.169		00
3899.463		000	3906.318		000
3899.530	Mn	0	3906.438	Co	2
3899.701	Mn	0 N	3906.539		000
3899.850	Fe	8	3906.628	Fe	10
3899.963		0 N	3906.763		00
3900.361		0	3906.890	Fe	4
3900.470		000	3907.099		1
3900.549		0	3907.251		0 N d?
3900.681	Ti-Fe-Zr	5	3907.368		00
3900.797		000	3907.433		000
3900.907		000	3907.615	Fe-Sc	3 d?
3900.973		0	3907.807		1
3901.114	Ti	1	3907.910		1
3901.197		000	3908.077	Fe	5
3901.297		00	3908.203		000
3901.474		00 N d	3908.310		0000
3901.621		00	3908.410		1
3901.735		2	3908.546		0
3901.878		000	3908.684		0
3902.002		3	3908.821		00
3902.114	Fe	1	3908.900	Cr	4
3902.241		0	3909.064		1
3902.399	V	3	3909.211		000
3902.567		1 N	3909.423		0
3902.768		2 N	3909.538		0000
3902.916		0	3909.638		00
3903.090	Fe-Cr	10	3909.802	Fe	4
3903.216		0	3909.863		000
3903.302		1	3909.976	Fe	5
3903.398		2	3910.079	Co-Ca	3 N d?
3903.553		000	3910.211		000
3903.683		00 N d?	3910.348		000
3903.868		000	3910.469		2
3903.991		2	3910.615		0
(3904.023)		8 d	3910.670		2
3904.052	Fe	5	3910.802		0
3904.213	Co	0	3910.984	Fe-V	4
3904.467		00	3911.135		3
3904.613		000	3911.230		00
3904.767		0	3911.316	[1] Nd	0
3904.926	Ti	3	3911.444		000

[1] Nd is the symbol for Neodymium.

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PLATE IV

SOUTH

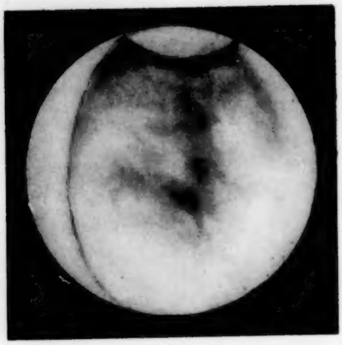


FIG. 1
1894, May 25, 5h. 0m. a. m. Melbourne Mean Time. Long. 114°. Power 280.

FIG. 2
1894, May 26, 5h. 25m. a. m. Melbourne Civil Time. Long. 110°. Power 280.

FIG. 3
1894, May 29, 5h. 50m. Melbourne Civil Time. Long. 87°. Power 280.

FIG. 4
1894, May 30, 6h. 15m. a. m. Long. 83°. Power 330.

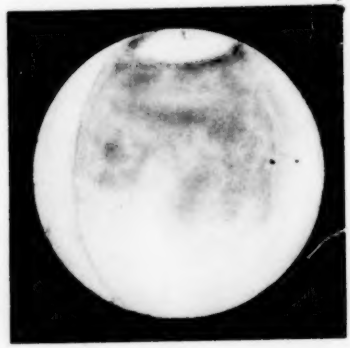


FIG. 5
1894, June 7, 6h. 40m. a. m. Melbourne Civil Time. Long. 10°. Power 330.

NORTH

DRAWINGS OF MARS

Made with the Melbourne 4-foot Reflector

By PIETRO BARACCHI

OBSERVATIONS OF MARS MADE IN MAY AND JUNE, 1894, WITH THE MELBOURNE GREAT TELESCOPE.[1]

By R. L. J. Ellery.

May 25.—This is the first clear morning after May 21. Clear; heavy dew falling. Bad definition. Best power 280. The first general impression is as follows:

Gibbosity on *p* side conspicuous. The South Polar Cap, is an elliptical area, dazzling white, with sharp contour, not a speck visible in it; all along its northern side it is bordered with a dark narrow strip which is conspicuous. Faint dark patches of irregular, unrecognizable form extend from the border over a considerable portion of the southern half of the planet, a central marking, darker than the other, extending farther north.

The *f* limb is very brilliant; the terminator is dusky on the southern part and generally dull, but of sharp contour. All the bright parts of the planet are of a bright rose-orange. The markings show no particular color, and look like pencil markings made on orange-tinted paper.

Unsteadiness very persistent and troublesome.

The sketch shows the appearance of the planet as seen by occasional glimpses of steadiness between 4.50 and 5.10.

May 26.—Clear; frosty; heavy dew falling.

Image very unsteady. Best power 280.

The northern border of the South Polar Cap does not seem so much curved as on May 25, the curvature being very slight this morning. The area, however, is about the same. Markings very faint and indistinct; they seem to change strangely, and it is difficult to preserve any definite impression.

Color and general character of image much the same as on May 25.

[1] Communicated by Professor W. H. Pickering.

Sketch, from impressions obtained by occasional moments of steadiness, from $5^h 20^m$ to $5^h 30^m$.

May 27 and 28.—Overcast.

May 29.—Clear in parts. Thin moving banks of haze. Image extremely unsteady. Now and then there come moments of good definition, and a glimpse of the real image is obtained. The contour of the South Polar area is very sharp. Nothing to be seen within the area, which is always dazzling white. The coloring is the same as on previous nights.

May 30.—Cloudy. The planet is only visible in occasional breaks. Generally unsteady and not quite clear; but on two occasions I got a moment of very good definition and steadiness. There is a dash appearing on the *s* limb, near the *f* corner of the Polar Cap. This is the first marking seen on the area.

May 31 to June 6.—Overcast and raining.

June 7.—Partly cloudy. Clouds rolling on the surface as I watch it. The South Polar area is smudged on the *p* corner, as if the dash seen yesterday morning traveled to the opposite corner.

June 7 to 14.—Overcast and raining. No more observations made.

General Remarks Applying to All the Observations.—The following limb and also the northern parts of the planet, were always very bright, and of a rose-orange color. The South Polar Cap was white both before and after sunrise. No change of color was observed in daylight except the orange became more rosy.

The area on June 7 seemed smaller than on May 25. Markings on sketches are drawn darker and slightly more pronounced than as seen originally.

RECENT CHANGES IN THE SPECTRUM OF NOVA AURIGÆ.

By W. W. Campbell.

Some interesting and significant changes have occurred recently in the spectrum of *Nova Aurigæ*. The intensities of at least two of the prominent bright lines have decreased very materially. They are the lines at λ 4360 and λ 5750. The variations will be realized best if we tabulate, as below, the intensities of the principal lines as estimated in 1892, and of the same lines as estimated quite recently.

	$H\gamma$	λ4360	$H\beta$	λ4960	λ5010	λ5750
1892, August and September[1]	0.1	0.8	1	3	10	1
1894, May 8	0.1	0.3	1	3	10	0.4
1894, September 7	0.1	0.2	1	3	10	0.4
1894, November 28	0.1	0.1	1	3	10	0.3

It will be seen that the change in λ 5750 is very decided, and that the change in λ 4360 is radical. The wave-lengths of both these lines were observed visually in August, 1892, with comparative ease. The line λ 4360 is now so faint that it can be seen only with great difficulty, and the line λ 5750 is probably too faint to measure.

On the spectrum photographs taken early in September, 1892, the line λ 4360 was by far the brightest line of all, *being certainly eight times as bright as $H\gamma$*. I have just secured another photograph of the spectrum (November 28), and it shows that λ 4360 *is now fainter than $H\gamma$*.

It is especially interesting that the lines λ 4360 and λ 5750 should be the ones to change. The first measures of the spectrum in August, 1892, showed unmistakably that it was the spectrum of a nebula. At first the lines λ 4360 and λ 5750 did not seem to exist in the old nebulæ. However, photographs of their spectra showed the line λ 4360 in five well-known nebulæ;

[1] For the estimated intensities of the nineteen lines observed in 1892, see *Pub. A. S. P.* **4**, 245.

and careful visual observations showed the line $\lambda\,5750$ in three nebulæ. These lines were strong in the *Nova*, but relatively faint in the old nebulæ. They have now become relatively faint in the *Nova*!

The spectra of the well-known nebulæ likewise have their anomalies. The lines $\lambda\,4472$ and $\lambda\,4687$ not only have very different intensities in different nebulæ, but they seem to be entirely absent from some nebulæ. The new star seems to be fast losing its anomalies; its spectrum is not only nebular, but it is approaching the *average type* of nebular spectrum.

The observed intensities of the line $\lambda\,4360$, recorded in the above table, show that the decrease has been gradual rather than sudden.

The lines still remain broad, as they always have been described.

I have measured the wave-lengths of the two principal lines recently, with the following results:

$$1894,\ \text{September } 7,\ \begin{cases} \lambda = 4958.7\,;\ v = -18^{\text{km}} \\ \lambda = 5006.4\,;\ v = -36^{\text{km}} \end{cases}$$

$$1894,\ \text{November } 28,\ \begin{cases} \lambda = 4958.8\,;\ v = -12^{\text{km}} \\ \lambda = 5006.8\,;\ v = -15^{\text{km}} \end{cases}$$

These measures were made with reference to the iron line at $\lambda\,4957.6$ and the lead line at $\lambda\,5005.6$. With the micrometer wire in the positions of these lines it was seen with perfect ease that the star lines were less refrangible than the comparison lines. In August and September, 1892, the star lines were seen, on the contrary, to be much more refrangible than these same comparison lines.

On the 1894, November 28, negative the wave-length of the $H\gamma$ line is 4340.3, corresponding to a velocity of -28^{km}. Its wave-length on the 1892, September, negatives was 4335.8. The wave-length of $H\gamma$ has therefore changed just as have those of the three principal lines. The wave-length of the line $\lambda\,4360$ on the recent negative is 4364. On the 1892, September, negatives it was 4359. Thus this line has also shifted, as we would expect, along with the others.

As bearing upon any possible theory of *Nova Aurigæ*, perhaps it will not be out of place to say here what I said last winter in another journal.[1] The Harvard College Observatory has shown that both *Nova Aurigæ* and *Nova Normæ* at discovery possessed substantially identical spectra of bright and dark lines, similarly and equally displaced. Both diminished in brightness and both assumed the nebular type of spectrum. The new star of 1876 in *Cygnus* probably had nearly an identical history: passing from a bright star with a spectrum of bright and dark lines, to a faint object with a spectrum consisting of one bright line (undoubtedly the nebular line λ 5010, or the two nebular lines λ 5010 and λ 4960 combined). We may say that only five "new stars" have been discovered since the application of the spectroscope to astronomical investigations, and that three of these have had substantially identical spectroscopic histories. This is a remarkable fact. We cannot say what the full significance of this fact is. One result, however, is very clear: the *special* theories propounded by various spectroscopists to account for the phenomena observed in *Nova Aurigæ* must unquestionably give way to the more *general* theories.

MT. HAMILTON, November 30, 1894.

[1] *Pub. A. S. P.* **6**, 52, 103.

THE MODERN SPECTROSCOPE. X.

GENERAL CONSIDERATIONS RESPECTING THE DESIGN OF ASTRONOMICAL SPECTROSCOPES.

By F. L. O. WADSWORTH.

The special requirements which an astronomical spectroscope has to fulfil in addition to the usual ones possessed by the best laboratory instruments, are:

1. The greatest possible degree of compactness consistent with a given degree of resolving power, which is usually determined in advance by the character of the work which is to be done with the instrument.

2. The highest possible efficiency as regards loss of light by reflection and absorption in the passage of the beam through the spectroscopic train, be it grating or prismatic.

3. Lightness combined with an unusual degree of stiffness and rigidity between the various parts of the instrument and the telescope to which it is attached. Ease of attachment to and detachment from the latter is also of importance, particularly in the case of large instruments.

To meet most satisfactorily these conflicting requirements in any particular case is a matter of some difficulty, and demands in the first place, careful consideration of the theoretical principles involved, some of which do not seem to be well understood by astronomers in general; and in the second place, no small degree of skill in optical and mechanical design. We will briefly consider these points in this, their relative order of importance.

A. THEORETICAL CONSIDERATIONS.[1]

In every case there must be a given condition as a starting point from which to work, and this will most naturally be a given degree of resolution, since upon this depends,

[1] When this paper was written I did not know of the very excellent and complete paper by Professor Keeler (*Sidereal Messenger*, November, 1891), on the same subject.

not only the purity of the spectrum, but also, in the case of a bright line spectrum at least, its brightness.[1] The condition of a constant resolving power is a much fairer basis upon which to compare the efficiency of different spectroscopes than the condition, sometimes taken, of a constant dispersion, no matter whether the instrument is to be used for visual, photographic or bolographic observations. In the latter two cases a large linear magnitude of the spectrum is necessary, because of the finite size of the silver grains in the one case, and the finite width of the bolometer strip in the other. But this may always be secured under any conditions of resolution and dispersion, by simply increasing the focal length of the observing telescope.[2]

In what follows then, we shall suppose always (unless otherwise stated), a fixed resolving power, which we will call r. Let R, A, F, denote respectively the resolution, aperture (linear) and focal length of the telescope objective; f, and a, and f', a', the cor-

It will be found that some of the conclusions reached, particularly in regard to the necessary size of instrument, differ from those of Professor Keeler. This and other differences are due in the main to the assumption of a different basis of comparison (constant dispersion as against constant resolution), and to the adoption of a different method of treatment (that of geometrical as against that of physical optics).

[1] In discussing this point, Schuster, in his article "Spectroscopy" (*Ency. Brit.* **22**, 374), says, "We come then to the conclusion, that for both narrow and wide slits the efficiency of a spectroscope depends exclusively on its resolving power." See also, Rayleigh, "Investigations in Optics with Special Reference to the Spectroscope." *Phil. Mag.*, **8**, 261, 403, 407; **9**, 40, 1879–80.

[2] Linear magnitude of the spectral image must be carefully distinguished from dispersion, of which, as stated above, it is entirely independent. The dispersion is properly defined as the ratio between the change in the angle of deviation θ and the corresponding change in wave-length, *viz.* by $\frac{d\theta}{d\lambda}$. It is, therefore, entirely independent of the focal length of the observing telescope, and depends only upon the optical properties and arrangement of the spectroscopic train.

It is similarly equally independent of the resolving power R, any value of the one being obtainable with any value of the other. With a given prism, for example, any value of the dispersion from a certain minimum (the dispersion at minimum deviation) to ∞ may be obtained by simply changing the angle of incidence, while the resolving power is only slightly changed, *i. e.* diminished, by the operation. It would seem that there ought to be no confusion as to the obvious distinctions between these three quantities, but they are nevertheless often confounded.

responding quantities for the collimator and observing telescope of the spectroscope ;

$$\psi=\frac{a}{f}\,,\ \text{and}\ \beta=\frac{a'}{f'}\,,$$

the angular apertures of the collimator and observing telescope ; ω, the angular magnitude of the source of radiation; s, the width and h the height of the illuminated portion of the slit ; D, the dispersion of the spectroscopic train ; P, the purity of the spectrum ; i, its intensity, and b its intrinsic brightness. Further, in the case of the grating, let m denote the order of the spectrum observed; n, the number of lines in the grating of an aperture equal to a; q, the grating interval; θ, the angle of diffraction, and i the angle of incidence. In the case of the prismatic train, ϕ denotes the refracting angle of the prism, or prisms, if more than one is used ; θ, the angle of deviation of the refracted beam at minimum deviation; n, the index of refraction and N the number of prisms in the train.

The most important consideration which will determine the resolving power r of any particular instrument will be the size (*i. e.*, linear aperture) of the telescope with which it is to be used; for r should in general be proportional to R, and this, for any particular part of the spectrum, is simply proportional to A. When the resolving power r is once determined by this general principle, modified in special cases by the conditions of use, the focal length of the collimator of the spectroscope, which is the chief factor in determining the size of the latter, becomes determined by the relation

$$f=a\frac{F}{A}\,.$$

Since the resolving power r depends, in the case of a grating, only upon the total number of lines and the order of the spectrum, and in the case of a prism, only upon the difference between the thicknesses of refracting media traversed by the two extreme rays, it follows that we may obtain a given degree of resolution, either, 1) by the use of a small aperture a with a very finely ruled grating, or a large number of prisms; or 2) by the use of a large aperture, with a more coarsely ruled grating, or a smaller

number of prisms. Since the bulk, weight, and, roughly, the cost of the whole instrument is proportional to the cube of the aperture, while the rigidity obtainable with a given construction is inversely proportional to it, the advantage of keeping this as small as possible is readily appreciated. It becomes then a question of some importance to determine the relation between the aperture a and the dispersion, purity and brightness of the resultant spectrum.

It may be readily shown that for any given value of r, the dispersion D is, in the case of both the grating and the prismatic spectroscope, inversely proportional to the aperture a.

In the case of a grating, resolution is defined by the well-known relation $r = mn$, and since $a''(\sin\theta + \sin i) = mn\lambda$, we have at once

$$D = \frac{d\theta}{d\lambda} = \frac{mn}{a''\cos\theta} = \frac{mn}{a},$$

since $a''\cos\theta = a' =$ effective aperture of the observing telescope, and therefore of the spectroscope.

Hence, disregarding the small difference between a and a', consequent upon rotating the grating for different portions of the spectrum, we have

$$D = \frac{r}{a}.$$

In the case of the prism, we have similarly,

$$r = (t_1 - t_2)\frac{dn}{d\lambda},$$

where t_1 and t_2 are the greatest and least thicknesses of refracting medium traversed by the extreme rays;

$$\therefore t_1 - t_2 = Na\frac{2\sin\frac{\phi}{2}}{\sqrt{1 - n^2\sin^2\frac{\phi}{2}}},$$

and

$$r = 2Na\frac{\sin\frac{\phi}{2}}{\sqrt{1 - n^2\sin^2\frac{\phi}{2}}}\frac{dn}{d\lambda}.$$

But the dispersion

$$D_1 = \frac{d\theta}{d\lambda} = \frac{d\theta}{dn}\frac{dn}{d\lambda} = \frac{d}{dn}\left(\qquad \right)\frac{dn}{d\lambda},$$

and

$$D_n = N\frac{2\sin\frac{\phi}{2}}{\sqrt{1 - n^2\sin^2\frac{\phi}{2}}}\frac{dn}{d\lambda},$$

$$\therefore D = \frac{r}{a}$$

as before.

The purity P of the spectrum is independent of the aperture under the conditions of constant resolution. For purity is defined by the relation
$$P = \frac{\lambda}{d\psi + \lambda} r ,$$
and hence if $d\psi$ and r are constant, P is also constant. It follows at once from this that for any given telescope (ψ=constant), and for any given degree of purity, *the slit width and therefore the total energy of the beam incident on the collimator is the same for all apertures; i. e., for all focal lengths of the collimator.* Hence, disregarding for a moment the losses due to transmission through the spectroscopic train, it also follows that the total energy in the spectral image of the slit, whether continuous or discontinuous, will be a constant, and will be equal to Ish, where I is a factor depending on the intensity of the source of radiation, the aperture A and the focal length F of the large telescope. The intensity i of the image will be measured by the ratio between the area of the slit hs and the area of its image $h's'$, and is therefore equal to
$$i = I\epsilon \frac{hs}{h's'} ,$$
ϵ being the factor of loss of energy by absorption, reflection, diffusion, etc., during transmission. In order to more completely define this ratio we need to express the value of $h's'$ in terms of hs and ψ and β. It is evident that
$$s' = \frac{f'}{f} s + E + H + G ,$$
where E is the effective broadening of the image due to the effect of diffraction; H, the effective broadening due to the dispersion; and G that due to chromatic and spherical aberration, imperfection of optical surfaces and irregularities of dispersion produced by differences in density in the case of the prism train or by unequal spacing in the case of the grating.

Similarly
$$h' = \frac{f'}{f} h + E + G' ;$$
$$\therefore\ i = I\epsilon \frac{sh}{\left(\frac{f'}{f} s + E + H + G\right)\left(\frac{f'}{f} h + E + G'\right)} . \qquad (1)$$

The relative importance of the different terms in the denominator will depend upon the character of the spectrum under examination, the width of the slit s, and upon the quality of the instrument itself. In general in any good instrument G and G' may be neglected in comparison with the others. Usually also the height h is large in comparison with the width s, and also in comparison with E; and the expression (1) therefore reduces to

$$i = I\epsilon\left(\frac{f}{f'}\right)^2 \frac{s}{s + \left(\frac{f}{f'}\right)[E+H]} = I\epsilon\left(\frac{\beta}{\psi}\right)^2 \frac{1}{1 + \frac{\beta}{s\psi}[E+H]}, \qquad (2)$$

in which the value of the terms E and H must now be considered for particular cases.

If the aperture is circular, the diffraction image of a vertical line (the bounding edge of the slit, for example) at the focus of the observing telescope, will be a band, the intensity of which at any point will be given by the expression

$$I = \frac{1}{4}\,\frac{\pi^2 a^4}{\lambda^2 f'^2}\,\frac{J_1^2(z)}{z^2}\text{, where } z = \frac{\pi a x}{\lambda f},$$

x being the distance from the center of the image of the line and $J_1(z)$ is Bessel's function of order unity. Tables of the values of $J_1^2(z)z^{-2}$ have been given by Lommel,[1] from which the curve, Fig. 1, is plotted. The value of x for which I becomes zero is given by the roots of the equation $J_1(z)=0$, the first of which gives

$$X = 1.22\frac{\lambda}{a}f' = 1.22\frac{\lambda}{\beta}.$$

The total broadening of the slit image, due to diffraction from both edges, is therefore[2]

$$2X = 2.4\frac{\lambda}{\beta}.$$

[1] SCHLÖMILCH, **15**, 166, 1870. See "Wave Theory," Rayleigh: *Ency. Brit.*, **24**, 432.

[2] The intensity of the first bright lateral band (see Fig. 1) is only about $\frac{1}{60}$ the intensity at the center, and it is therefore insensible to the eye or to the photographic plate under ordinary conditions.

It must be noted that the curve, Fig. 1, does not truly represent the falling away in intensity at the edges of the image of a slit of finite width, for in that case the diffraction figure is one produced by the superposition of the diffraction images of every

But, owing to the rapid fading away of intensity at the edges of the image, the apparent broadening visually or photographically will be somewhat less than this, not more than $X = 2\frac{\lambda}{\beta}$.

The equivalent broadening may, so far as its effect on the intensity is concerned, be considered to be

$$X_o = E = ab = \frac{\lambda}{\beta},$$

such that the area, *abcd* (Fig. 1), is equal to the total shaded

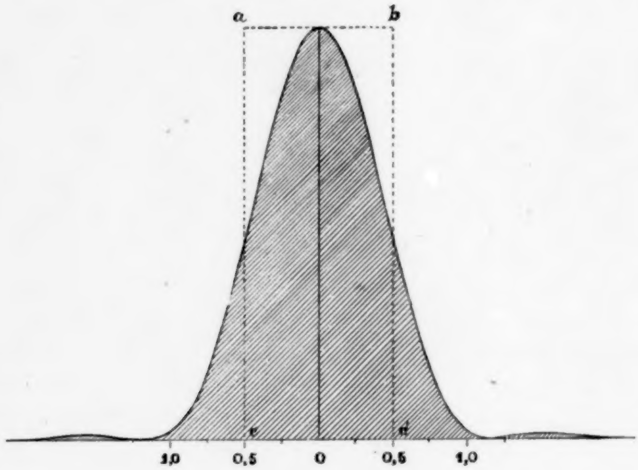


Fig 1

area under the curve, between the limits $x = +\infty$; $x = -\infty$, *i. e.*, to

$$\int_{-\infty}^{+\infty} Idx .$$

For an aperture $\beta = \frac{1}{10}$, which is not far from the usual value for an observing telescope, and $\psi = \frac{1}{15}$, we have

$$\frac{\beta}{\psi} E = \frac{\lambda}{\psi} = 0^{mm}.0075 \text{ or } 0.0003 \text{ in.}$$

a quantity that can only be neglected when the slit-width is greater than $\frac{1}{1000}$ in.

element of the slit. If, however, we disregard the effect of the first lateral band, it does truly represent the extreme broadening of the image at its edges, which is what we are concerned with here.

In what precedes we have been considering the slit image as of uniform brightness across the whole width of the slit. There is one case of great importance in which this is not true, *i. e.*, that of stellar images. Here the image of the star is so small that it falls entirely within the slit, and the effective width and height of the latter is simply the diameter of the star image. This will evidently be $s = h = \omega F + X$, where ω, as already defined, is the angular magnitude of the star, and

$$X = 2.4 \frac{\lambda}{A} F = 2.4 \frac{\lambda}{\psi} .$$

Since the intensity at the edge of the disk will be very small, we may for practical purposes write

$$s = h = \frac{\omega A + 2\lambda}{\psi} = \frac{2\lambda}{\psi} .$$

In the case of large telescopes s is from $0^{mm}.015$ to $0^{mm}.020$.[1]

The apparent (visible) broadening X' of the spectral image by the diffraction of the observing telescope will in this case be considerably less than where the slit image is of uniform intensity across its entire width. It will, of course, vary with the absolute brightness of the star image, but will not in the majority of cases exceed one-half that found in the former case, or

$$X' = \frac{\lambda}{\beta} .$$

The effective broadening X_0' of the spectral image is similarly less, and may be taken in this case as simply equal to X', since the intensity of the slit image itself varies according to the law $I = f(x)$, shown in Fig. 1.

$$\therefore \; E = X' = \frac{\lambda}{\beta} ; \quad s = h = \frac{2\lambda}{\psi} .$$

Substituting these values in (1) (neglecting the terms G and G'), we have therefore, in the case of stellar spectra, to a high degree of approximation,

$$\left.\begin{aligned} i &= \frac{2}{3} I\epsilon \left(\frac{\beta}{\psi}\right)^2 \frac{s}{s + \frac{\beta}{\psi}\left[\frac{\lambda}{\beta} + H\right]} \\ &= \frac{1}{2} I\epsilon \left(\frac{\beta}{\psi}\right)^2 \frac{1}{1 + \frac{\beta H}{3\lambda}} \end{aligned}\right\} \qquad (3)$$

In considering the effect of H, the broadening of the spectral image due to dispersion, two cases must be distinguished. First, that in which the value of H is small in comparison with usual values of s, which is the case of discontinuous or line-spectra; second, that in which H is large, compared with s, the case of a continuous spectrum.

[1] Star images generally appear larger than this because of the unsteadiness of the air and consequent "boiling" of the image.

1. Discontinuous (line) spectra. No source of radiation is absolutely monochromatic, but sends out waves which have a certain range of wave-lengths lying between limits λ_1 and λ_2 which we may designate by $\Delta\lambda = \lambda_1 - \lambda_2$. The resultant broadening (linear) of the image by dispersion will therefore be

$$Z = f' \frac{d\theta}{d\lambda} \Delta\lambda = \frac{r}{\beta} \Delta\lambda.$$

The equivalent broadening Z_0, *i. e.*, the broadening which would produce the same diminution in intensity if the spectral image were uniformly bright clear across, will be less than this, because the intensity of radiation falls off from the center of the line towards the edges, probably according to an exponential law; and the intensity at the edges of the dispersed spectral image will therefore fall off according to a similar law. As the form of the curve is not very different from the diffraction curve already described, Z_0 may be considered to be about $\frac{1}{2}$ Z, or

$$Z_0 = H = \frac{r\Delta\lambda}{2\beta} .$$

In order to get an idea of the magnitude of the effect involved, let us consider some special cases of bright lines whose width is known.

Michelson's recent work[1] has given us an exact knowledge of the width and distribution of intensity in a number of the bright lines of metallic spectra. The effective width of the line *w*, *i. e.*, the extreme values λ_1, λ_2, between which the range $\Delta\lambda$ must be taken, will vary (as in the case of the diffracted image of a star) with the absolute brightness of the slit image, but it will not in general be much greater or much less than four times what Michelson calls the half-width of the line δ, *i. e.*, the value of x for which the intensity,

$$\left(\phi(x) = e^{-\frac{p^2}{a^2}x}\right)$$

is one-half the maximum intensity. The following table gives the value of δ (in tenth-meters) as determined by Michelson for a number of the more simple lines in the spectra of cadmium, zinc,

[1] "Application of Interference Methods to Spectroscopic Measurements, II." A. A. Michelson: *Phil. Mag.*, September, 1892.

thallium and sodium, under different conditions, and, for the red hydrogen line, at different pressures up to about one-eighth of an atmosphere.

The table also contains the values of Z and Z_0 in mm for a value of $r = 25{,}000$,[1] computed on the assumption that the effective width w is 4δ, and that the aperture of the telescope β or ψ is $\frac{1}{18}$.

TABLE I.

LINE	CONDITION	δ tenth-meters	$w = 4\delta$	$Z = \frac{r}{\beta} w$	$H = \frac{1}{2} Z$
Cd_r	Vacuum tube, temp. about 280°.	.0065	.026	mm.0010	mm.0005
Cd_g	Vacuum tube, temp. about 280°.	.0050	.020	.0008	.0004
Zn_r	Vacuum tube, temp. about 350°.	.0130	.052	.0020	.0010
Na_y	Vacuum tube	.005	.020	.0008	.0004
	Bunsen flame	.05	w' .27 *	.0101	.0050
Tl_g	$TlCl_3$ in vacuum tube	.004	.016	.0006	.0003
	$TlCl_3$ in Bunsen flame	.04	w' .27 *	.0101	.0050
H_r*	Vacuum tube, pressure 0mm . . .	.047	w' .328*	.0123	.0062
	Vacuum tube, pressure 10mm . . .	.054	.356*	.0134	.0067
	Vacuum tube, pressure 25mm . . .	.073	.432*	.0162	.0081
	Vacuum tube, pressure 50mm . . .	.098	.532*	.0200	.0100
	Vacuum tube, pressure 75mm . . .	.118	.612*	.0230	.0115
	Vacuum tube, pressure 100mm . . .	.134	.696*	.0261	.0130

The importance of the term H on the intensity of bright line spectra increases rapidly with the increase of pressure in the source of radiation, and with the resolving power of the spectroscope employed.

In the case of the bright line spectra of the solar prominences, nebulæ and certain bright line stars, but little is known

[1] This resolving power (that of a grating with 20,000 lines to the inch and $1\frac{1}{4}$ in. aperture) is larger than is ordinarily used in stellar spectroscopic work, but is quite commonly exceeded in solar work.

* The red hydrogen line is a double, the distance between the components being about .14 tenth-meters. The value of δ is for each component, and the total effective width of the double line is therefore, $w' = w + .14$. The same is true of each of the sodium and of the thallium lines, but in this case, only one of the components is considered. The distance between the centers of the components is in the case of the sodium lines about 0.07, and in the case of the thallium lines about 0.11. When the density is low (vacuum tube), these components are therefore separated by much more than their own width, but when it is high (as in the Bunsen flame), each component broadens and overlaps the other, so that the total effective width is, as in the case of the hydrogen line, $4\delta + a$, where $a = 0.07$ and 0.11 in the two cases respectively.

of the actual "width" of the lines, and the value of H is, therefore, uncertain. The width of the reversed (bright) K line in the prominence spectrum has in certain cases been found to be about 0.2 tenth-meters. With a spectroscope of the resolving power and angular aperture just assumed, the value of Z will therefore be

$$Z = 25000 \times 15 \times .2 \times 10^{-7} = .0075$$
$$\therefore H = 0^{mm}.0037.$$

In most cases the resolving power of an astronomical spectroscope will be considerably lower than this, so that even if $\Delta\lambda$ is in particular cases much larger, the resulting value of H will in general be small compared with the slit-widths which it is generally necessary to use. An important exception to this is found in the case of the spectra of nebulæ, which will soon be considered.

We have already found that the value of E is about .0075 (for $\beta = \frac{1}{18}$), or in the case of star spectra about $\frac{1}{2}$ this amount, ($0^{mm}.004$). In most cases these quantities may be neglected in comparison with s, and the expression for i becomes simply

$$i = I\epsilon\left(\frac{\beta}{\psi}\right)^2.$$

Under conditions of constant magnification $\left(\frac{\beta}{\psi}\right)$ becomes constant, and the brightness b of the spectrum, as viewed by the eye, is therefore nearly constant for all apertures and for all slit-widths greater than $0^{mm}.025 = 0.001$ in. For widths less than this it is necessary to consider also the effect of the terms H and E.

It is evident that the maximum intensity at the central portion of the image will be reached when the width s is equal to

$$\frac{\beta}{\psi}\left(\frac{X}{2} + Z\right).$$

But (see preceding footnote)

$$X = \frac{2\lambda}{\beta}, \text{ and (see above) } Z = \frac{r}{\beta}\Delta\lambda;$$

$\therefore$ for maximum intensity (or brightness)

$$s = \frac{\lambda}{\psi} + \frac{r}{\psi}\Delta\lambda. \qquad (4)$$

Substituting this value of s in the expression for the purity, we have for the condition of maximum brightness and maximum purity

$$P_b = \frac{\lambda}{2\lambda \times r\Delta\lambda} r,$$

which shows that the purity of the spectrum can never, even with an absolutely monochromatic source, exceed 50 per cent. of the resolving power, unless the brightness be sacrificed by making the angular width of the slit less than the angle subtended by a wave-length of light at a distance equal to the aperture a of the collimator.[1]

To obtain an idea of the relative importance of the term $r\Delta\lambda$ as compared with λ, let us consider the case of a solar prominence line observed, as before, with a spectroscope of resolving power $r = 25000$. We have then

$$r\Delta\lambda = 25000 \times 2 \times 10^{-8} = .0005 = \lambda;$$

or, in this case, the width of the slit which gives maximum illumination is twice as great as that given by the limit $s = \frac{\lambda}{\psi}$. With still higher resolving powers, or larger values of $\Delta\lambda$, the importance of the second term with respect to the first becomes even greater than this. In the case of the nebulæ, for example, it is found that the brightness of the lines of the spectrum continues to increase until the slit-width is from $1\frac{1}{2}$ to 3 or 4 times (according to the resolving power employed) as great as what has been (erroneously) regarded as the theoretical slit-width for

[1] It is usually stated that the width of the slit for maximum illumination is $s = \frac{\lambda}{\psi}$, and that the increased brightness actually observed when the slit is widened beyond this point is only apparent, and due to physiological causes. Schuster (*Ency. Brit.*, **22**, 374) says: "The maximum illumination for any line is obtained when the angular width of the slit is equal to the angle subtended by one wave-length at a distance equal to the collimator aperture. In that case $d\psi = \lambda$ . . . If the visual impression depended only on the intensity of illumination, a further widening of the slit should not increase the visibility of a line. As a matter of fact, spectroscopists generally work with slits wider than that which theoretically gives full illumination. The explanation of the fact is physiological, visibility depending on the apparent width of the object." It is evident, however, from the preceding, that $s = \frac{\lambda}{\psi}$ is not the true limit of slit width for maximum illumination, but there is an actual increase of brightness up to the point $s = \frac{1}{\psi}(\lambda + r\Delta\lambda)$.

maximum intensity. If observations of the relative intensity of the central portion of the spectral image with different widths of slit were made with sufficient accuracy, with a bolometer or photometer, for example, we could determine from the above relation the value of $\Delta\lambda$, and hence obtain some knowledge of the conditions of temperature and pressure in these distant masses of gas.[1] For if we call s_0 the value of s for which the intensity becomes constant, we have from (4)

$$\Delta\lambda = \frac{s_0\psi - \lambda}{r} .$$

The only observations on s_0 which are immediately available are those of Keeler on the Orion Nebula.[2] Professor Keeler says: "Experiment showed, however, that with the same exposure the density of the photographed lines began to fall off sensibly when the slit-width was reduced below .001 in., or when it was still three times the theoretical width." (The theoretical width here referred to is that given by Schuster). . . . . The discrepancy is, I suppose, to be attributed to the spreading of the photographic image; . . . . the physiological effect which makes a line appear brighter when the slit is widened in visual observations seems to be analogous to this photographic action. The slit-width which gave the best results was about 0.0015 in."

If we take s_0 to be 0.001 in. $=$ $^{mm}.025$ (allowing 0.0005, or $\frac{1}{3}$, of the increased effect as due to photographic irradiation), we have for $\Delta\lambda$

$$\Delta\lambda_0 = \frac{0.025\,\psi - .0005}{r} .$$

In Professor Keeler's instrument with which these observations were made, $\psi = \frac{1}{14}$, and r (a single 60° prism of white flint, with an aperture of 1.13 in., was used) was about 5000.[3] We have, therefore, $\Delta\lambda_0 = 2.6$ tenth-meters, or nearly four times the width of the red hydrogen line at a pressure of 100^{mm}.

If the preceding data are trustworthy, this result indicates either that the pressure is much greater than is ordinarily supposed, or that the whole mass

[1] A much better method is, of course, to examine these radiations by means of a small wave comparer, attached to the observing telescope in place of the usual eye-piece or photographic plate. A preliminary trial of this method has already been made by Michelson and Hale on the bright lines of a solar prominence with very promising results, although the particular apparatus used was ill adapted to the purpose, and further experiments have therefore been postponed until a more suitable instrument can be constructed.

[2] "On the Spectra of the Orion Nebula and the Orion Stars," J. E. Keeler, *A. and A.*, October, 1893.

[3] Calculated from data given by Professor Keeler, in a paper describing the Allegheny spectroscope. — *A. and A.*

of the gas in the nebula is in a state of violent agitation (which would broaden the lines by reason of varying velocities in the line of sight). Or it might indicate that the lines themselves, which appear to be single, are in reality made up of a number of components. Further theorizing on the question is useless until more exact data are obtained by one of the methods previously indicated.

2) *Case of continuous spectra.* If $\Delta\lambda$ be large in comparison with λ, *i. e.*, if the source of radiation sends out waves whose length varies regularly and continuously from λ_1 to λ_2, the value of H becomes so large that in comparison with it all the other terms in the denominator may be neglected. In this case, if we suppose the intensity uniform from end to end of the spectrum,

$$H = Z = \frac{r}{\beta}(\lambda_1 - \lambda_2)\ .$$

We then obtain from (2)

$$i = I\epsilon \frac{\beta^2}{\psi^2} \frac{s}{\left(\frac{\beta}{\psi}H\right)} = I\epsilon \left(\frac{\beta}{\psi}\right)^2 \frac{s\psi}{r(\lambda_1 - \lambda_2)}\,, \qquad (5)[1]$$

which shows that in this case the intensity is proportional to the width of the slit s, and inversely proportional to the resolution. But it also shows that for a given purity P ($s\psi$=constant), and given resolution r, the intensity, just as in the case of the discontinuous spectrum, is independent of the aperture a. Hence the brightness under constant magnification will also be independent of the aperture and hence of the dispersion of the spectroscope.

The only difference, therefore, between this and the preceding case is that in the first the intensity and brightness is independent of the slit-width (above a certain minimum width, whose value has been already discussed), and in the second, both of these quantities are directly proportional to the slit-width.

In the comparison of spectroscopes of different focal lengths but of constant resolving power, it only remains to determine the relative losses during transmission of the beam through the spectroscopic train, so far as these are affected by a change of aperture. As regards these losses we have unfortunately very

[1] In the case of star spectra the formulæ are the same with the exception of the factor [illegible] [see (3)].

little data in the case of either the prismatic or the grating train. In the former case the loss during transmission is made up of two factors: one, the loss by absorption in the refracting media, the other, the loss by reflection from the surfaces of the prisms. The loss by absorption may easily be shown to be the same for all apertures, since the thickness of refracting media traversed by the different rays is in each case the same.[1] The relation between the index of refraction and the absorption, either total or local, has been experimentally determined only in the case of very few kinds of glass, and even for those, not with a sufficient degree of completeness. It is to be hoped that experiments will soon be made for the sake of more completely determining this relation. The second element of loss by reflection increases as the aperture diminishes; for, as we have already seen, the number of prisms N, and hence the number of reflecting surfaces[2] varies inversely with the aperture a. This loss, however, increases much less rapidly than the number of prisms, because after the first few reflections the light becomes almost completely polarized at right angles to the plane of incidence, and is therefore almost completely transmitted by the succeeding surfaces. For the sake of a more complete representation of this important fact, the following brief table, abridged from tables which I have recently prepared, is presented. It gives the per cent. loss of light by reflection in the case of a prism train consisting of N prisms of flint glass ($N_D = 1.6$) of 64° angle, on the assumptions: 1) that the incident light may be regarded as made up of

[1] PICKERING (*Am. Jour.*, **14**, 1868) makes the following statement, which has been quoted in Scheiner's *Astronomical Spectroscopy* (Frost's translation):

"In spectroscopes of the same *dispersion* and from the same glass the loss of light by absorption is the same." This is evidently only true for the special case in which the two spectroscopes have the same aperture. The more general principle is that given above; *viz.*, that the absorption is the same (for any given kind of glass) in all spectroscopes having the *same resolving power*, no matter what the dispersion or the aperture.

[2] The number of reflecting surfaces $= 2N$, in case the train is a single transmission one of simple prisms, and $= 4Q(N+2)$ if the train is a multiple transmission one of the Littrow or modified Littrow type, and is made up of compound prisms, Q being the number of times the beam passes through the train.

two beams of equal intensity polarized at right angles to one another; 2) that the loss by reflection may be correctly represented by Fresnel's formula, and 3) that the angle of incidence is the angle of complete polarization, or so near it that the loss by reflection of that portion of the beam polarized at right angles to the plane of incidence may be disregarded. The total loss can therefore never exceed 50 per cent. In the case of prisms of white flint ($n = 1.6$) this last condition will be satisfied if the refracting angle of the prism is 64°, and very nearly satisfied if the refracting angle is 60° (see Table).

Table II.

Loss of Light by Reflection from the Surfaces of a Train of Prisms of 64° Refracting Angle and Index 1.6.

Number of Prisms	Number of Surfaces	Loss by Reflection	Per cent. of Total Loss	Loss by Reflection for Prisms of 60° [1]
1	2	.174	35	.147
2	4	.287	57	.252
3	6	.361	72	.328
4	8	.409	82	.382
5	10	.441	88	.422
10	20	.493	98	.504
∞	∞	.500	100	—

It appears from the above table that more than $\frac{1}{3}$ the total loss of light is caused by the first prism, and that very little additional loss is caused by the addition of any number of prisms after the third, provided only that condition 3) is satisfied.

As regards the loss of light in the case of a grating, we have still less data, either theoretical or experimental, to guide us. The loss by diffusion will in general tend to increase with the closeness of the ruling, but it may easily happen that this may be more than counterbalanced by the more perfect concentration of the light in one particular spectrum.[1] Irregularities of spac-

[1] From Pickering's Tables. *Amer. Jour.*, **45**, 1868.

[1] The concentration of the light in any particular spectrum is dependent only upon the form of the cross section of the rulings. This is not at present, nor is it likely soon to be, a determinate problem constructively; although gratings are often obtained, either accidentally or by trial settings of the ruling point, which show a high degree of efficiency in this respect.

ing, however, have a much more injurious effect upon definition, and therefore upon purity, in finely than in coarsely ruled gratings; and for this reason it is very difficult to produce a satisfactory grating with more than 1500 lines to the mm. ($q = 0^{mm}.00067$).

So far we have considered the case of a constant angular aperture, $\psi = \frac{A}{F}$, of the telescope, and a constant degree of resolution r. Let us see what will be the effect of varying either or both of these quantities.

1. *Effect of varying* ψ. It is evident that the effect of changing ψ is simply to change the value of I, the intensity of the image on the slit. In considering this effect it is necessary to distinguish between those cases in which ω, the angular magnitude of the source, is insensible, and those in which it has a considerable value. In the first case the energy-gathering power, and therefore the total energy in the image, will increase in the ratio A^2, while the area of the image will increase in the ratio

$$\left(\frac{\omega A + 2\lambda}{\psi}\right)^2.$$

The mean intensity of the image I will therefore vary as

$$\left(\frac{A}{\omega A + 2\lambda}\right)^2 \psi^2 \quad \text{or} \quad I = k\,\frac{A^2}{(\omega A + 2\lambda)^2}\,\psi^2,$$

where k is an absolute constant depending for its value only on the intensity of the source of radiation. The effective width of the slit is in this case simply the diameter of the image, which is, as we have just seen, $\frac{\omega A + 2\lambda}{\psi}$.

The purity of the spectrum is therefore constant, for

$$P = \frac{\lambda}{s\psi + \lambda}\,r = \frac{\lambda}{\omega A + 3\lambda}\,r,$$

and ωA is always small compared to 3λ.

Under the condition of constant purity we have, therefore, for the intensity from (3) and (5):

a) For continuous spectra

$$i = \frac{2}{3} I\epsilon \left(\frac{\beta}{\psi}\right)^2 \frac{s\psi}{r(\lambda_1 - \lambda_2)} = \frac{2}{3} k\epsilon\beta^2 A^2 \frac{1}{2r\lambda(\lambda_1 - \lambda_2)}; \qquad (6)$$

b) For discontinuous spectra

$$i = \frac{1}{2}\, I\epsilon \left(\frac{\beta}{\psi}\right)^2 \frac{1}{1 + \frac{\beta H}{3\lambda}} = \frac{1}{2} k\epsilon\beta^2 A^2 \frac{1}{2\lambda(2\lambda + \frac{1}{3} r\Delta\lambda)}. \tag{7}$$

That is, the intensity is in all cases independent of the angular aperture ψ, but increases as the square of the linear aperture A of the telescope. The necessity for a large aperture in order to obtain brilliant stellar spectra is at once evident. In order, however, to obtain pure spectra a large resolving power is absolutely necessary, for, as we have just seen,

$$P = \frac{\lambda}{\omega A + 3\lambda} r,$$

and the purity of the spectrum can therefore never exceed one-third of the theoretical resolving power. This explains to some degree the want of sharpness always observed in stellar spectra, even when viewed under the most favorable conditions.

If we follow the rule proposed in the first of this article, and make the resolving power of the spectroscope proportional to the aperture of the telescope, then $r = r_0 A$, where r_0 is the resolving power for unit aperture. Under these circumstances we have for i,

$$i = \frac{2}{3} k\epsilon\beta^2 \frac{A}{2r_0\lambda(\lambda_1 - \lambda_2)} \quad \text{for continuous spectra;}$$

$$i = \frac{1}{2} k\epsilon\beta^2 \frac{A}{2\lambda\left(\frac{2\lambda}{A} + \frac{1}{3} r_0\Delta\lambda\right)} \quad \text{for discontinuous spectra;}$$

which shows that under these conditions the intensity increases in a somewhat smaller ratio than the aperture (because of the increase of ϵ with r, on account of the additional losses, due to absorption, reflection and diffusion, which attend the use of a larger aperture and a higher resolving power).

Equations (6) and (7) show that the intensity (and therefore brightness) of the spectrum varies inversely as the wave-length. In the case of prismatic spectra this is compensated by the fact that the resolving power of a prism varies inversely as the cube of the wave-length. In the case of the continuous spectrum, equation (6) becomes, therefore,

$$i = K\frac{\lambda^2}{r_\lambda},$$

where r_λ is the resolving power of the instrument for some particular part of the spectrum. In addition to its higher efficiency as regards the concentration of light in only one spectrum, the prism train has therefore this other important advantage over the grating for the purposes of photography, *viz.*, the more uniform distribution of actinic intensity in the spectral image.

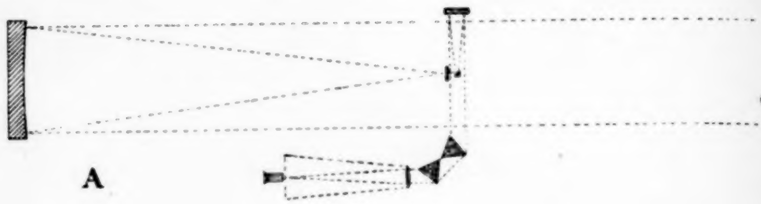
The preceding considerations indicate the correct lines for the construction of star spectroscopes, which strangely enough do not seem to have been generally understood, or at least regarded in the design of existing instruments, perhaps because it has always been necessary to use them on existing telescopes. The importance of the work, however, would now certainly seem to warrant the use of specially constructed image lenses or condensers instead of the usual telescope objectives, which are usually considerably more accurately corrected than they need be for this work, and could therefore be more advantageously used for other purposes. The image-forming lens or "condenser" of a star spectroscope should have: 1) The largest possible linear aperture A, in order: a) to increase the intensity of the star image; b) to increase the value of the term ωA in comparison with λ, and thus secure a more uniform distribution of intensity across the breadth of the image. 2) A very large angular aperture ψ, *i. e.*, a very short focal length F, in order to make the width of the image

$$\left(\frac{\omega A + 2\lambda}{\psi}\right),$$

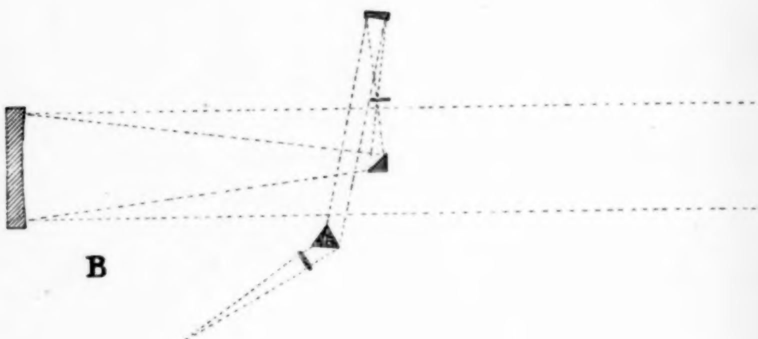
and therefore the effective width of the slit, as small as possible, and also in order to make the whole arrangement as compact as possible. These two requirements are best met by the use of a parabolic mirror, which has the further advantage of having no chromatic aberration and requiring no change of focus for different wave-lengths.

It does not seem at all impossible to make such reflectors (silver on glass) with a linear aperture of 6, 8, or even 10 feet, with a focal

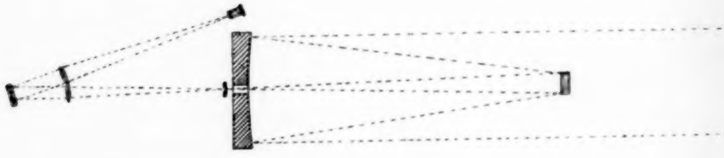
PLATE V



A



B



C

length only three to four times the aperture.[1] This would require the use of a concave (parabolic) mirror in place of a lens for the collimator of the spectroscope, but as I have already pointed out,[2] this is attended by no disadvantages; on the contrary, it has certain advantages, even when the image is formed out of the axis of the mirror.

In Plate V, *A*, *B*, *C*, are shown diagrammatically some forms of stellar spectroscopes designed on the above lines. If it is considered desirable to use a lens instead of a mirror for the collimator, this may be done by the introduction of a convex mirror (or concave lens) in the cone of rays before they reach the focus (as in Plate V, *C*), although this can only be done at a sacrifice of the sharpness and brightness of the star image. On this ground forms *A* and *B* are certainly to be considered preferable.

If the angular value ω of the source be so large that the width of the image s' be greater than the width of the slit s, ωA becomes large compared with λ, and the ratio

$$\left(\frac{A}{\omega A + 2\lambda}\right)^2 \text{ becomes simply } \left(\frac{1}{\omega}\right)^2, \text{ and therefore}$$

$$I = \frac{k'}{(\omega)^2}\psi^2 = k\psi^2.$$

In this case the purity of the spectra will vary with ψ in the ratio

$$\frac{\lambda}{s\psi + \lambda}.$$

It may, therefore, be maintained constant in either one of two ways: 1) By diminishing the width of the slit s, as the angular aperture ψ increases, so that the product $s\psi$ remains constant.

[1] The large reflecting telescope made by Mr. Brashear for the Smithsonian Astrophysical Observatory has an aperture of 50^{cm} and a focal length of only 1 meter, *i. e.*, the ratio of focal length to aperture is only 2 to 1. This instrument gives very satisfactory definition, better in fact than would be necessary for its use as a condenser.

[2] "An Improved Form of Littrow Spectroscope;" F. L. O. Wadsworth, *Phil. Mag.* July, 1894. I have since learned that this form of spectroscope had been previously suggested by Lippich and Ebert in the *Zeit. für Inst.* It is also now being used by Messrs. Kayser and Runge (see Pulfrich, *Zeit. für Inst.*, October, 1894). I regret that I did not know of the papers of the gentlemen first mentioned at the time of writing the article, so that I might have accorded them the claim of priority.

2) By increasing the resolution, as ψ increases in the proportion $s\psi + \lambda$, s remaining constant.

By the first method we diminish the intensity (of a continuous spectrum) in the ratio $\frac{1}{\psi}$ by closing the slit; by the second we diminish it in a somewhat smaller ratio:

$$\frac{1}{s\psi + \lambda},$$

by an increase in r, but the gain in the last case is counterbalanced by the increased loss due to greater absorption or diffusion, so that the final result is about the same in either case.

We have, therefore, under the condition of constant purity, as before:

a) For continuous spectra,

$$I = k\psi^2 \text{ and } \begin{cases} s = s_0\psi \text{ for constant resolution,} \\ r = r_0(s\psi + \lambda) = r_0(s\psi) \quad \text{for constant slit-width.} \end{cases}$$

$$\left.\begin{aligned} \therefore\ i &= I\epsilon\left(\frac{\beta}{\psi}\right)^2 \frac{s\psi}{r(\lambda_1 - \lambda_2)} = k\epsilon\beta^2 \frac{s_0}{r(\lambda_1 - \lambda_2)}, \text{ for } r = \text{const.} \\ i &= I\epsilon\left(\frac{\beta}{\psi}\right)^2 \frac{s\psi}{r(\lambda_1 - \lambda_2)} = k\epsilon\beta^2 \frac{1}{r_0(\lambda_1 - \lambda_2)}, \text{ for } s = \text{const.} \end{aligned}\right\} \quad (8)$$

b) For discontinuous spectra,

b_1) For wide slits (greater than $0^{mm}.02$)

$$i = I\epsilon\left(\frac{\beta}{\psi}\right)^2 = k\epsilon\beta^2; \quad (9)$$

b_2) For narrow slits (less than $0^{mm}.02$)

$$i = I\epsilon\left(\frac{\beta}{\psi}\right)^2 \frac{s}{s + \frac{1}{\psi}\left(\lambda + \frac{r\Delta\lambda}{2}\right)} = k\epsilon\beta^2 \frac{1}{1 + \frac{2\lambda + r\Delta\lambda}{2s_0}}; \quad (10)$$

which shows that in this case the intensity is independent both of the angular aperture ψ and the linear aperture A of the telescope, and, with a given observing telescope and a given spectroscope, depends, as before, only upon the value of k, that is, upon the intensity of the source of radiation.

Equation (10) shows that in the case of bright line spectra from sources having a considerable angular magnitude (nebulæ,

comets, solar prominences, faculæ, etc.) the intensity and, therefore, brightness will necessarily diminish as the resolving power increases. Pure spectra can then only be obtained when the source is very bright, and a small telescope is just as advantageous as a large one in viewing the spectra of such objects.

Use of the telescope objective as a (so-called) "condensing" lens.—Since the intensity of the spectrum of a source having a finite angular magnitude is independent both of the angular aperture ψ and the linear aperture A of the telescope, it is evident that the term "condenser" is in this case inappropriate. Indeed, we may reduce the latter to infinitesimal dimensions, or, what practically amounts to the same thing, dispense with it altogether without loss of light, provided only: 1. That the angular magnitude ω of the source is equal to the angular aperture ψ of the collimator; 2. That the source is of uniform brightness; 3. That the form of the source is geometrically similar to the aperture of the spectroscope.

The resulting spectrum is necessarily the resultant or integrated effect from all parts of the surface, and it will, therefore, be more or less impure, according as the radiation conditions of different portions of the source differ from each other. Thus, in a solar spectrum formed by such a spectroscope, the dark lines will all be broadened by an amount equal to

$$\frac{r}{\beta}\,\Delta\lambda_v\,,\ \text{where } \Delta\lambda_v$$

is the difference in the wave-lengths of a given radiation from the east and west limbs of the Sun, produced by reason of the rotation of the latter with velocity v. If we assume the equatorial velocity to be about 2^{km} per second, $\Delta\lambda_v$ is about .08 tenth-meters, or an amount equal to about $\frac{1}{3}$ the breadth of one of the sodium lines at atmospheric pressure. If the highest degree of purity is required, the use of an image lens or condenser is, therefore, indispensable. But it may also be shown that, in the case of the Sun or other heavenly body surrounded by an absorbing atmosphere, the use of a condensing lens is necessary, in order to secure the maximum intensity of spectrum. This may be shown as follows:

Let σ denote the quantity of energy received normally per unit area at the surface of the Earth from unit area of the Sun. Then the total energy received per unit area from all parts of the Sun's disk will be, since the angular magnitude of the radiating surface is small,

$$p = \int\int \sigma dx dy\,;$$

or, if we suppose the falling off in intensity to be symmetrical about the center, more simply

$$p = 2\pi \int_0^R \sigma x dx,$$

R being the radius of the solar disk.

If no condenser is used, and the spectroscope train has an aperture of sufficient size to receive all the light which passes through the slit, the total energy incident on the collimator will evidently be

$$P = sh2\pi \int_0^R \sigma x dx \ .$$

If a condenser is used, the energy transmitted to the image on the slit from each element of the solar surface will be $q = \frac{1}{4}\epsilon\pi A^2\sigma$, and if, again, the spectroscope has an angular aperture large enough to transmit all the light received from the slit,[1] the total energy incident on the collimator will, in this case, be

$$Q = \frac{\epsilon\pi A^2}{4} \int_{y_2}^{y_1} \int_{x_2}^{x_1} \sigma dx dy \ ,$$

where x_1, x_2, and y_1, y_2, are, respectively,

$$x_1 = \frac{D}{F}\xi_1 \ , \quad x_2 = \frac{D}{F}\xi_2 \ ,$$

$$y_1 = \frac{D}{F}\zeta_1 \ , \quad y_2 = \frac{D}{F}\zeta_2 \ ,$$

ξ_1, ξ_2, and ζ_1, ζ_2, being, respectively, the coördinates of the horizontal and vertical edges of the slit referred to the center of the solar image as origin, and D, the distance of the Sun. If the solar image is placed symmetrically on the slit, and its diameter is not greater than the length of slit opening, we have simply

$$x_1 = -x_2 = \frac{D}{F}\frac{s'}{2} \ ;$$

$$y_1 = -y_2 = \frac{D}{F}\frac{h'}{2} = R \ .$$

Further, the width of the strip the coördinates of whose edges on the solar surface are x_1, x_2, is so small that in the integration for x, σ may be considered constant. A first integration gives us then

$$Q = \tfrac{1}{4}\epsilon\pi A^2 \frac{D}{F} s' \int_{-R}^{+R} \sigma dy = \tfrac{1}{2}\epsilon\pi A^2 \frac{D}{F} s' \int_0^R \sigma dy \ ,$$

and therefore

$$\frac{Q}{P} = \frac{\epsilon}{4} \frac{s'\psi AD \int_0^R \sigma dy}{sh \int_0^R \sigma y dy} \ . \tag{9}$$

[1] If the diameter of the solar image on the slit plate is small, compared with the focal length of the collimator, we must have, in order to fulfil this condition, $a' = f\psi + h$. Hence the angular aperture (vertical) of the spectroscope must be

$$\psi' = \frac{a'}{f} = \psi + \frac{\omega F}{f} \ ,$$

while the horizontal aperture will be as before,

$$\psi = \frac{a}{f} = \frac{A}{F} \ .$$

To determine the value of this ratio in any particular case we must know the law of variation of σ or the form of the function $\sigma = \phi(y)$. In the case of the Sun, the experiments of Vogel[1] show that for the brightest part of the spectrum, the curve of $y = \phi\sigma$ is very nearly a circle having its center coincident with the center of the disk.[2]

Hence, if σ_0 denote the intensity of radiation at the center, the intensity σ at any part of the Sun's disk in terms of the distance y from the center will be very nearly

$$\sigma = \sigma_0 \sqrt{R^2 - y^2}\,.$$

Substituting this value for σ, and integrating, we obtain for the two preceding integrals

$$\int_0^R \sigma dy = \frac{\sigma_0}{4} \pi R^2\ ;$$

$$\int_0^R \sigma y dy = \frac{\sigma_0}{3} R^3\ .$$

Substituting these values in (9), we obtain

$$\frac{Q}{P} = \frac{3}{16} \pi \epsilon \frac{s'\psi}{sh} \frac{AD}{R} = \frac{3}{8} \pi \epsilon \frac{s'\psi}{s\omega} \frac{A}{h}\ .$$

But for constant purity of spectrum in the two cases we must have equivalent slit-widths, or

$$s' = \frac{\omega}{\psi} s \qquad \therefore s'\psi = \omega s\ ;$$

and we have simply for constant purity

$$\frac{Q}{P} = \frac{5}{4} \epsilon \frac{A}{h}\ ;$$

that is, for an aperture of the condenser equal to the height of the slit used without a condenser, the intensity of the spectral image will (neglecting the absorption of the glass of the condenser) be about 25 per cent. brighter with the condenser than without. If we are concerned not with the brightness of the spectrum but with the total intensity in the image of any one line, as in bolometric work, for example, the immense advantage of the use of the condenser is evident whether the radiating surface be of uniform brightness or not.[3] For it is possible to make the aperture A at least ten times as great as the greatest possible length of slit which can be used without a condenser, (on account of the necessary limitations in size of prisms and focal length of collimator). We can, therefore, by the use of the latter, obtain under the

[1] These experiments were confirmed in a striking manner and by an entirely different method by Michelson in his measurements of the angular diameter of the Sun's image by interference methods.—See "Application of Interference Methods to Astronomical Measurements," A. A. Michelson, *Phil. Mag.*, July, 1890.

[2] Figures 4 and 5, *Ibid.*

[3] If σ is constant, the ratio $\frac{Q}{P}$ reduces to simply $\epsilon\frac{A}{h}$, which shows that the brightness of the spectral image is the same with a condenser as without (or slightly less, on account of the absorption of the additional lens).

same conditions of resolution, purity and longitudinal magnification, a spectral image whose height,[1] and therefore total intensity, is from ten to twelve times greater than could possibly be obtained without it. To increase the intensity per unit width to any required degree, it is only necessary to contract the spectrum vertically by using a cylindric lens of proper curvature, placed with its axis at right angles to the length of the slit, either in front of the latter or between the objective of the view telescope and its focal plane. The former position is always preferable when the best definition is desired (as in photographic work), although it increases the necessary vertical aperture of the spectroscope by an amount inversely proportional to the distance of the cylindric lens from the slit.

The use of the condenser has the further advantage that with it much smaller focal lengths may be used, and the whole instrument thereby made more compact and manageable. A practical illustration will perhaps bring out these points more clearly. The largest optical prism which has yet been made, so far as I am aware, is one recently furnished by Brashear for the Smithsonian Astrophysical Observatory. It is made of rock-salt from a block exhibited by the Russian government at the World's Fair, and has a clear horizontal aperture of about $9\frac{1}{2}^{cm}$ and a vertical aperture of 19^{cm}. When no condenser is employed, the greatest height of slit which can be used with this prism without loss of light is a little less than 10^{cm}. The necessary focal length of the collimator is $\frac{9.5}{\omega} = 11^{m}$, or about 35 feet. The height of the spectral image with an observing telescope of say 2^{m} focal length will be about $1\frac{3}{4}^{cm}$. Now if instead of this arrangement we use a condensing lens of say 50^{cm} aperture and 4^{m} focal length, the height of the slit, in this case the diameter of the solar image, will be reduced to about $3\frac{1}{2}^{cm}$. For the same horizontal aperture of prism as before, the focal length of the collimator will be only $\frac{3}{4}^{m}$ and its vertical aperture will be about 13^{cm}, instead of 19^{cm} as before. The height of the spectral image, for the same observing telescope as before, will be about 9^{cm}, and the total energy will be over six times as great as before.

These conclusions have all been verified experimentally both in the visible and in the infra-red spectrum by means of a bolometer placed at the focus of the observing telescope.

The experiments were made with condensing lenses of different apertures and different focal lengths under the conditions of constant resolution and constant purity, *i. e.*, with the same prism, and with a slit-width inversely proportional to the angular aperture of the condenser, and hence directly proportional to the focal length of the collimator (the horizontal aperture of the

[1] We have $h' = h\frac{\psi}{\beta} = \frac{\omega}{\beta}A$ or for a given aperture of the observing telescope, the height of the spectrum is directly proportional to the aperture of the condenser.

latter remaining constant). The same observing telescope was used in each case, and a cylindric lens with its axis at right angles to the refracting edge of the prism was placed just in front of the focal plane, in order to reduce the height of the spectrum in each case to the length of the bolometer strip (about 1^{cm}).

B. MECHANICAL CONSIDERATIONS.

No discussion is necessary to show that all mechanical considerations are favorable to a reduction in the size of the instrument to the lowest possible limit consistent with its efficient performance. From our preceding discussion of the theory of the spectroscope under the condition of constant resolving power, we have seen that the only decrease in efficiency which accompanies a decrease in size is that due to a slight additional loss of light (by increased diffusion, due to a finer ruling in the case of the grating, and by an increased number of reflections in the case of the prism train), and a possible impairment of definition, in the case of the grating, by the increased effect of the unavoidable errors of spacing[1] when the grating space becomes very small. The limit to reduction in size is in all cases determined not by this reduction in efficiency, which is comparatively slight, but by mechanical and optical difficulties of construction. In the case of the grating, for example, it is practically impossible to rule a *satisfactory* grating with more than 40,000 lines to the inch, and even gratings with 30,000 lines are not commercially obtainable.

If we require, then, a resolving power of 25,000 in the first spectrum, we must use in the case of a grating spectroscope an aperture of at least $\frac{5}{8}$ inch. Granting, however, that a good grating of 40,000 lines per inch is available, a spectroscope of this size would be in every way as powerful and efficient as one with an aperture of $2\frac{1}{2}$ inches, using a grating of the ordinary fineness (10,000 lines per inch), and far more rigid and convenient to use, while the weight, bulk and (approximately at

[1] Even if the screw of the dividing engine were absolutely perfect, errors of spacing would still occur, due to inaccuracies in the slides which carry the ruling point, to changes of temperature, to differences in hardness of different portions of the ruled surface, to slight errors in the surface, and to many other causes.

least) the cost of the smaller instrument will be only $\frac{1}{64}$ that of the larger one.

The same considerations hold with respect to the prismatic form. Here the number of prisms (of any particular kind of glass, and of any given refracting angle) requisite to secure a given degree of resolution varies inversely as the aperture. The reduction in aperture is, then, in this case only limited by the number of prisms which it is possible to employ. With prisms of dense flint of 60° angle, the resolving power is about 4000 per inch of aperture for a single prism. To obtain a resolving power of 25,000 with an aperture of $2\frac{1}{2}$ inches would, therefore, require three prisms. To obtain the same degree of resolution with an aperture one-quarter as large, *viz.* $\frac{5}{8}$ inch, would require, therefore, twelve prisms. The volume of glass required would, however, be only one-sixteenth as great, and the total area of optical surface one-quarter as great.

The definition would be likely to be better the smaller the instrument, because the glass would be more homogeneous in small than in large blocks, the small surfaces could be more accurately worked, and with a large number of surfaces the errors would tend to compensate each other. The increase in the loss of light by reflection, in using twelve rather than three prisms, would be only 14 per cent. of the incident light (see Table I), while the loss by absorption would be the same. The principal mechanical difficulty is in mounting the prisms and automatically maintaining them at minimum deviation, with a sufficient degree of accuracy for the purposes of mechanical measurement. Usually, however, this is not necessary, accurate measurements being usually made by means of a standard comparison spectrum, which is observed at the same time, or photographed on the same plate.

The limit to reduction in size of aperture is, then, in this case even lower than in the case of the grating spectroscope. For by adopting the multiple transmission form of spectroscope (the original Littrow, or better, Young and Lockyer's modifica-

tion of it),[1] there is no difficulty in using the equivalent of twenty or thirty prisms, and thereby obtaining a resolving power of from 50,000 to 60,000 with a $\frac{5}{8}$ inch aperture, or from 30,000 to 35,000 with only a $\frac{3}{8}$ inch aperture. There is in this case, however, considerable additional loss by the repeated reflection of the beam by the reflecting mirrors, or right-angled prisms, at the ends of the train.

UNIVERSITY OF CHICAGO,
November, 1894.

[1] See Schellen, *Spectralanalyse*, **1**, 231.

A very compact form of an instrument of this type has been made by Grubb (*M. N.*, **31**, 36.)

These forms and others have been discussed by the author in the paper already referred to. (*Phil. Mag.*, July, 1894.)

Minor Contributions and Notes.

THE ASTROPHYSICAL JOURNAL.

In a paper bearing the above title, published in the first number of *Astronomy and Astro-Physics* (January, 1892), the reasons which had prompted the publication of a journal of astronomical physics were enumerated, and evidence was adduced to show that considerable support might be expected for such a venture. It had been my intention to establish a separate astrophysical journal, but the uncertainty of such an undertaking led to an acceptance of Professor Payne's proposal of a union with the *Sidereal Messenger*, and *Astronomy and Astro-Physics* was the result. The contents of the thirty numbers published during the three years which have elapsed since that time offer sufficient testimony to the usefulness of the composite journal. From the outset the editorial supervision of the departments of *General Astronomy* and *Astro-Physics* was kept entirely distinct. The policy of the latter department was determined by myself and my associates, Professors Keeler, Crew and Ames, while the selection of all other matter published in the journal was made by Professor Payne and those who were associated with him. No attempt was made to draw a hard and fast line between the two departments. Had this been done, and a strict definition of "astrophysics" adhered to, a large part of the matter published under *General Astronomy* would have appeared in the other department of the journal. It was thought best, however, to confine the scope of *Astro-Physics* to the more technical subjects connected for the most part with spectroscopic work.

In returning to the original idea of a purely astrophysical journal we are simply following out a long-cherished plan. Few who appreciate the true scope of astrophysics, and have its best interests at heart, will deny the advisability of devoting an entire journal to this, the most fascinating and at the same time the most rapidly advancing department of astronomical research. In spite of the existence of physical and astronomical journals of the highest class, the astrophysicist or spectroscopist is at a loss to know where to publish in order to reach the audience he desires. Should he choose an astro-

nomical journal, he will find that his paper will remain unread and unknown by a very large majority of physicists — the very men who are, perhaps, best competent to appreciate its true value. A purely physical journal is not less evidently an unsuitable place for papers treating of solar or stellar investigations, even though these investigations be prosecuted by the methods of the physical laboratory. Recent papers on the radiation of gases and the validity of Kirchhoff's law have all appeared in physical journals, but the subject is one not less interesting to the astronomer than to the physicist. The same might be said of scores of other papers dealing with spectroscopic, bolometric, radiometric, photographic and photometric researches conducted in the laboratory, but finding their most important applications in the elucidation of astronomical phenomena. The astronomer and physicist should be able to meet on common ground, and this only an astrophysical journal can supply.

During a recent visit to many of the observatories and spectroscopic laboratories of Europe the writer enjoyed an excellent opportunity to discuss with both astronomers and physicists the plan of founding such a journal. At Potsdam Professor H. C. Vogel, Director of the Astrophysical Observatory, and Professors Scheiner, Müller and Kempf were found to be heartily in favor of the proposed journal and ready to promise their support and coöperation. In a plan of publication formulated at Berlin it was decided that five Associate Editors be chosen to represent Germany, Great Britain, France, Italy and Sweden on the editorial staff, for it was felt from the first that unless the journal were made truly international in character it could not be a success. Professor Vogel readily consented to be the Associate Editor for Germany. In subsequent visits to Rome, Paris and London the plans of the journal were discussed at length with Professor P. Tacchini, Professor M. A. Cornu and Dr. William Huggins. Everywhere the most cordial assurances of support and coöperation were received, and before my return to America the general plan of the journal had been decided upon, and the European members of the Board of Associate Editors chosen as follows: Professor M. A. Cornu, École Polytechnique, Paris; Professor N. C. Dunér, Astronomiska Observatorium, Upsala; Dr. William Huggins, Tulse Hill Observatory, London; Professor P. Tacchini, R. Osservatorio del Collegio Romano, Rome; Professor H. C. Vogel, Astrophysikalisches Observatorium, Potsdam. Subsequently five Associate Editors were secured

in the United States: Professor C. S. Hastings, Yale University; Professor A. A. Michelson, University of Chicago; Professor E. C. Pickering, Harvard College Observatory; Professor H. A. Rowland, Johns Hopkins University; Professor C. A. Young, Princeton University.

Professor James E. Keeler, of Allegheny Observatory, whose association in the editorial management of *Astronomy and Astro-Physics* had done so much for that journal, agreed to join the writer in editing THE ASTROPHYSICAL JOURNAL. Professor Henry Crew, of Northwestern University, and Professor Joseph S. Ames, of Johns Hopkins University, will continue the valuable work they have hitherto carried on in connection with *Astronomy and Astro-Physics* as Assistant Editors of the new journal, and Professor F. L. O. Wadsworth, of the University of Chicago, Professor Edwin B. Frost, of Dartmouth College, and Professor W. W. Campbell, of the Lick Observatory, have promised to assist in the same capacity. In addition to this exceptional editorial coöperation—in itself quite sufficient to make THE ASTROPHYSICAL JOURNAL truly international in character—we are fortunate in having promises of assistance from many astronomers and physicists in Europe and America.

It must not be supposed that THE ASTROPHYSICAL JOURNAL will deal only with the astronomical applications of the spectroscope. On the contrary, the scope of the JOURNAL will be quite as broad as that of *Astronomy and Astro-Physics* has been, for while papers dealing only with questions of celestial mechanics and measures of the positions of the heavenly bodies will not fall within it, they will be replaced by articles treating of laboratory researches closely allied to the investigations of astronomical physics. Drawings, photographs, descriptions and theories of the Sun, Moon, planets, satellites, comets, shooting stars, star clusters, nebulæ and the Milky Way will all be considered as coming within the scope of the new journal. So too will observations of variable stars, photometric determinations of stellar magnitude and planetary albedo, measurements of solar radiation and atmospheric absorption, observations of the phenomena of lunar and solar eclipses, and the numerous applications of the spectroscope in astronomy. The importance of supplying a common place of publication for papers on both the observatory and laboratory applications of physical methods of research has already been pointed out. For this purpose much space will be devoted to articles on wave-length determinations of the lines in solar, metallic, and gaseous spectra, bolometric and radiometric work, spec-

tral photometry, experiments on radiation and absorption, photographic researches in the infra-red and ultra-violet, studies of the relations of the lines in different spectra, interference and diffraction phenomena, and theoretical work in certain branches of optics, heat, electricity and other departments of physics. In pursuance of the plan which seems to have met with favor in *Astronomy and Astro-Physics*, the series of papers on the modern spectroscope will be continued, and accompanied by articles on telescopes, heliostats, bolometers, photometers and other instruments and apparatus used in such investigations as those mentioned above. Astrophysical and spectroscopic observatories and laboratories will also be fully illustrated and described.

Special attention will be given to the reproduction of the latest photographs of astronomical and physical phenomena. By reason of their relations with the observatories and laboratories of Europe and America, the editors will always have the best photographs at their disposal.

Articles written in any language will be accepted for publication, but unless a wish to the contrary is expressed by the author, they will be translated into English.

In the department of *Minor Contributions and Notes*, subjects other than those named in the above list of topics, but belonging to closely related fields of investigation, may find a place.

It is intended to publish in each number a bibliography of astrophysics, in which will be found the titles of recently published astrophysical and spectroscopic papers. In order that this list may be as complete as possible and that current work in astrophysics may receive appropriate notice in other departments of the JOURNAL, authors are requested to send copies of all papers on these and closely allied subjects to both Editors.

These and other details of the plan of publication of THE ASTROPHYSICAL JOURNAL were decided upon at a meeting of the American members of the Board of Editors held in New York on November 2, 1894. Professors Young, Pickering, Rowland, Michelson, Hastings, Keeler and Hale were present. It was voted that a meeting of the Board of Editors be held annually, for the discussion of matters relating to the JOURNAL.

Astronomy and Astro-Physics has been purchased from Professor Payne by the University of Chicago, and THE ASTROPHYSICAL JOURNAL will be practically a continuation of it in a slightly different form.

The annual subscription price (for ten numbers) is $4.00 for the United States, Canada and Mexico. In other countries of the Postal Union the price is 18 shillings, Subscriptions should be sent to *The University of Chicago, University Press Division, Chicago, Illinois.*

All European subscriptions should be sent to the sole foreign agents, *Wm. Wesley & Son, 28 Essex St., Strand, London.*

All papers for publication and correspondence relating to contributions should be addressed to *George E. Hale, Kenwood Observatory, Chicago, Illinois.*

GEORGE E. HALE.

NOTE ON THE ARC-SPECTRUM OF COPPER.

Messrs. Crew and Tatnall publish in *Astronomy and Astro-Physics*, **13**, 740, a method for obtaining the arc-spectra of metals free from carbon lines,[1] and as a specimen they give the spectrum of copper between $\lambda=4000$ and $\lambda=3600$. In this region they find 41 new lines, which have not previously been published as lines of copper. In our copper spectrum Professor Runge and I have recorded only those lines on the photographs which we were convinced belonged to copper. A good many other lines, not appearing on all the plates, especially not on the weaker ones, were omitted as doubtful. Among these I find 23 of the lines measured by Crew and Tatnall, and thus it becomes more probable that these 23 lines really belong to copper. I give here a list of these lines as measured by us:

3976.12	6 very hazy	3800.55	5 hazy	3695.42	5 hazy
3964.40	6 very hazy	3800.06	6 hazy	3685.05	6
3947.09	6 hazy	3797.29	6 hazy	3644.20	5 hazy
3933.20	6 hazy	3780.14	6 very hazy	3632.65	5 hazy
3881.80	6 hazy	3764.90	6 very hazy	3629.91	6
3817.45	6 very hazy	3721.76	6 very hazy	3610.86	5 hazy
3813.62	6 hazy	3720.84	6	3609.39	5
3803.62	6 very hazy	3699.19	5 hazy		

The concordance of our measurements with those of Crew and Tatnall is very satisfactory, considering that all the lines are very faint and hazy, and that only a few plates have been measured in both cases. Of the line 3619.52 Crew and Tatnall say: "surely not copper." This is, in fact, a very strong line of nickel. The line at 3961.64 is

[1] It is certainly a great advantage to avoid the carbon lines, but I fear that Messrs. Crew and Tatnall's method will be of use only in cases where the high temperature of the carbon arc is not needed.

perhaps the strong line of aluminium. We have never observed the other 16 lines of Crew and Tatnall, but this is, of course, no reason for attributing them to impurities, as a stronger current always brings out new lines.

H. Kayser.

ON DETERMINING THE EXTENT OF A PLANET'S ATMOSPHERE.

The early observations of the spectrum of *Mars*, made between 1867 and 1877, lead to substantially the same conclusion, viz.: the atmosphere of *Mars* is in a general way similar to our own. So far as I know, none of the observers formed, from the purely spectroscopic evidence, an estimate of the *extent* of the Martian atmosphere in terms of the extent of our own. The Moon and Mars were observed at equal altitudes, or in some cases with the Moon slightly lower than Mars. One observer saw one strong line and some faint lines in the planet's spectrum which were absent from the lunar spectrum. Another observer noted critical atmospheric and vapor bands in both spectra, but they were weaker in the lunar than in the Martian spectrum. A third observed bands in both spectra, but those seen in the lunar spectrum were fewer and narrower than those seen in the planet's spectrum. Thus the three observers agreed that the critical bands were stronger in the spectrum of the planet than in that of the Moon, and for the reason that in the former case the light had passed twice either partially or completely through Mars' atmosphere. Now if it be true that the critical bands are stronger in one spectrum than in the other, and, further, if Mars' atmosphere is similar to our own, it ought to be possible to equalize the critical bands in the two spectra by observing the Moon's spectrum when that body is considerably lower in the sky than Mars is. If we could find those (unequal) altitudes of the two bodies such that the two spectra were equalized, we could at once compute the relative quantities of our atmosphere and aqueous vapor passed through by the light from the two bodies. The difference of those relative quantities would be the relative quantity of atmosphere and aqueous vapor passed through on Mars by that planet's light, and would represent *considerably more than the maximum extent* of Mars' atmosphere. This method would be valuable not only because it would enable us to form an estimate of the extent of the atmosphere, but it would also furnish a most excellent test of the delicacy of the

spectroscopic observations themselves. It seems to me this method is well worth applying. In considering the physical problems relating to Mars it is important to know whether or not there is a Martian atmosphere; but it is no less important to know whether that atmosphere is very extensive or very thin.

W. W. CAMPBELL.

MT. HAMILTON, November, 1894.

THE CHICAGO ACADEMY OF SCIENCES.

SECTION OF MATHEMATICS, ASTRONOMY AND PHYSICS.

The regular monthly meeting was held December 11, at the Commerce Club, Auditorium building; Professor G. W. Hough, President, in the chair. After the transaction of routine business, the President introduced Dr. T. J. J. See, who presented a paper on "Helmholtz's Theory of the Heat of the Sun."

The speaker began by referring to Helmholtz's paper in the *Philosophical Magazine* for 1856, which he said appeared to be very little known to astronomers. In this paper the illustrious physicist had given the formulæ for computing the amount of heat developed by the condensation of the Sun, but had not shown how to derive the formulæ. The speaker proceeded to determine the potential of a sphere upon itself, and to derive the formulæ given by Helmholtz. It was shown, on reducing the formulæ to numbers, that the condensation of the solar nebula from infinity had produced enough heat to raise the temperature of a mass of water equal to the Sun to 27,000,000°C. As Pouillet had found by experiment that the heat annually lost by the Sun would raise the temperature of such a mass 1.25°C, it follows that the age of the Sun cannot surpass 21,600,000 years, if its radiation has been uniform at the present rate. The speaker did not believe the radiation had been uniform, and hence was of the opinion that the Sun was much older than this result indicated. He proceeded to show that a contraction of $\frac{1}{10000}$ part of the present radius would maintain the radiation for 2180 years; this corresponds to a change of 35 meters per year in the radius, and would of course be insensible for ages. It appeared that the condensation from infinity to the orbit of Neptune had produced only $\frac{1}{6600}$ part of the heat subsequently developed. All these results were true on the supposition that the Sun is homogeneous, but in the actual case heterogeneity will considerably

modify the results; the general effect of heterogeneity being to increase the total heat already lost by the Sun, and to lengthen its age by an unknown but considerable amount. In conclusion, the speaker regarded Helmholtz's theory as firmly established, but he took occasion to remark on the insufficiency of the older theories. He had found by calculation that if the Sun were pure carbon and pure oxygen in the right proportion to form carbon dioxide, the heat developed by the combustion of the entire mass would last only 1763 years. The meteoric theory was refuted on the ground that it required a sensible increase in the mass of the Sun, which would cause an acceleration in the mean motions of the planets — which has not been observed. In the discussion which followed, Professor Hough, Dr. Crew, Professor Chamberlin and Professor McNeill took part.

Professor Chamberlin discussed the bearing of the paper on geological theories, and thought the time given for the age of the Sun was much too short, as geological phenomena seemed to require at least 100,000,000 years for the age of the Earth.

Dr. See pointed out that the heterogeneity of the Sun must very considerably increase its past duration, and especially if it radiated more slowly than at present. He thought the solar system was likely to be more than 100,000,000 years old, and regarded Lord Kelvin's estimate as a fair approximation.

Dr. Crew thought modern estimates of the radiation would considerably modify the results of Pouillet. After considerable informal discussion, in which a number of members of the Academy participated, the meeting adjourned. σ.

WOLSINGHAM OBSERVATORY.

CIRCULAR NO. 41.

A very red 8 mag. IV type, not in DM., was found here last night at R. A. $17^h\ 54^m.3$; Dec. $+58^\circ\ 14'$ (1900).

T. E. ESPIN.

November 30, 1894.

Reviews.

On the Spectrum of the Electric Discharge in Liquid Oxygen, Air and Nitrogen. LIVEING and DEWAR. *Phil. Mag.*, August, 1894.

In these experiments sparks were passed through small layers of the liquified gases, one or both electrodes being immersed. When both electrodes were immersed there was a continuous spectrum, probably due to the heated particles which left the surface of the electrodes, and also a line and band spectrum due to the liquid itself. The lines were faint and few unless a Leyden jar was put in the circuit. These lines could nearly all be identified with the known lines of the gases. When one electrode was out of the liquid, more bands appeared, and various interesting changes took place. The most noteworthy observation made was that when sparks were passed through oxygen liquid and vapor, one electrode only being immersed, a band appeared between λ 5530 and λ 5610; and if a Leyden jar was put in the circuit, this band contracted to a line at about λ 5572. The wave-length of the Aurora line is λ 5571.6; and the conditions of temperature and pressure in these experiments must have been somewhat similar to those under which the Aurora appears. This points, of course, to the probability of the Aurora line being due to the oxygen of our atmosphere.

J. S. A.

On Variations observed in the Spectra of Carbon Electrodes, and on the Influence of one Substance on the Spectrum of another. W. N. HARTLEY. *Proc. R. S.*, **55**, No. 334.

In this paper Professor Hartley reiterates his belief that the so-called "cyanogen" bands are in reality due to the element carbon, not to a compound of carbon and nitrogen. He thinks that the differences between the "cyanogen" bands and the "carbon" bands are not too great to be accounted for perfectly by the variations in the external conditions under which the discharge passes between the carbon poles. He gives instances of many alterations produced by surrounding vapors and gases, and mentions the remarkable variations in intensity

of the lines of certain substances, produced by the addition of certain salts. These changes are undoubtedly real, and are most important; but it seems difficult to explain by means of them the enormous differences between the "cyanogen" and the "carbon" bands. In fact the arguments as to their nature which were summed up by Kayser and Runge, and which seem to show that we have in reality two distinct substances, are in no wise weakened by this article. It might be well to remark here that there is at the present time no more fruitful field open to research than that of the study of the influence of the presence of one substance upon the spectrum of another. J. S. A.

Flame Spectra at High Temperatures. II. and III. W. N. HARTLEY. *Proc. R. S.*, **56**, No. 337.

The first of these papers gives an abstract of a series of experiments upon the flame spectra of manganese and its compounds. The leading features of the spectra of the element and of its oxide are the same. One difference, however, should be noted. In the group of lines about λ 4030, the metal itself shows two bands closely adjacent, while the oxide gives what appears to be one band with a reversal down the middle, having the red side of the band sharp and strong, but the violet side very diffuse. This observation evidently has important bearing on the interpretation of Sun-spot spectra, where shadings occur on one side only of the metallic lines.

In the second paper are given some important observations on the phenomena, spectroscopic and chemical, of the Bessemer process. By far the most interesting fact noted is the appearance of certain hydrogen lines in the flame emitted during the first period of the "blow." Hartley records his results as follows: "During the first period: The lines of the alkali metals, sodium, potassium, and lithium, are seen unreversed on a bright continuous spectrum caused by carbon monoxide. The $H\alpha$ line of hydrogen, and apparently the $H\beta$ line, were seen reversed during a snowstorm." Watts had previously observed the $H\alpha$ line of hydrogen in the Bessemer flame during wet weather. If these observations can be accepted as definite, it would seem that the line spectrum of hydrogen can be produced, without the help of an electric discharge, at a temperature of about 1500° C. An unpublished observation of Professor Rowland's is of interest in this connection. He has noted at least once that in the metallic arc-spectra

a line appeared almost, if not quite, in the exact position of the $H\gamma$ line. He has not felt convinced that it was not an "impurity" line.

J. S. A.

Beiträge zur Kenntniss der Linienspectren. J. R. RYDBERG. *Wied. Ann.*, **50** (1893); **52** (1894).

In these contributions to our knowledge of the line spectra of the elements, Rydberg calls attention to the similarity between various families of these, emphasizing particularly the importance of the numerical value of the differences between the wave-numbers of the consecutive lines in the same series. From the analogy between the spectra of certain elements, he predicts lines of definite wave-length in the spectrum of one or the other element. He has given special attention to the lines of the spectra of calcium and strontium; and has made a more complete study of the grouping of these lines into series than has ever been done before. He seems to hope ultimately to be able to identify all the lines with series obeying the same law as the hydrogen lines. He says that he thinks he has given additional reasons for believing that there is only a single system of vibrations, and that all the lines of any one spectrum can be comprised in a single formula.

J. S. A.

Beiträge zur Kenntniss der Linienspectren. H. KAYSER u. C. RUNGE. *Wied. Ann.*, **52** (1894).

Under this title, the authors describe certain investigations prompted by the suggestion of Rydberg in his first series of *Beiträge*. They remark that the lines of the spectrum of magnesium which Rydberg thought formed a new series, cannot do so as they are so different physically. This emphasizes a warning to everyone who studies tables of wave-lengths instead of the spectra themselves. Kayser and Runge find, by careful study, certain additional lines and groups in the spectra of strontium, calcium, zinc and cadmium; all of which Rydberg had predicted from analogy. In order to see plainly one of the strontium groups, which came under the cyanogen band at λ 3800, Kayser and Runge weakened the effect of the carbon poles by passing a stream of CO_2 between them. When this was done, with strontium in the poles, a triplet was clearly photographed at λ 3865.59, 3807.51, 3780.58.

Although many lines predicted by Rydberg were found, some could not be, probably owing to lack of dispersion or to weakness of intensity.

J. S. A.

Ueber die Spectra von Zinn, Blei, Arsen, Antimon, Wismuth. H. KAYSER u. C. RUNGE. *Wied. Ann.*, **52** (1894).

This paper gives the result of the study of the arc-spectra of the elements named, and is a continuation of the authors' previous work on the spectra of the elements. Many new lines were discovered, and many important differences between the arc and spark-spectra are noted. These points of difference are extremely valuable. The authors naturally looked diligently for any series or regular arrangements of the lines, such as occur in the spectra of the elements of the first three of Mendelejeff's groups. Although they found nothing like these, they did discover that in the spectra of each of the elements studied there were certain groups of lines such that there was a constant difference between the wave-numbers of a line in one group and a line in the other. The lines in the groups thus correspond; and in one spectrum there may be as many as six groups, any two of which correspond. The lines forming any one group, however, do not seem to be connected by any mathematical or physical law. The number of lines which go to form these groups is too great to permit one to attribute them to chance, as Kayser and Runge prove quite conclusively.

J. S. A.

Preliminary Report on the Results Obtained with the Prismatic Camera during the Total Eclipse of the Sun, April 16, 1893. J. NORMAN LOCKER. (Abstract.)

The Total Solar Eclipse of April 16, 1893. Report on Results Obtained with the Slit Spectroscopes. E. H. HILLS.

The initial number of Volume 56 of the *Proceedings of the Royal Society* contains two reports on the results of the English spectroscopic observations of the total solar eclipse of April 16, 1893.

The first is an abstract of a preliminary notice by Lockyer on the results of the observations with the prismatic camera. This instrument, of six inches aperture, and provided with a prism of 45° angle, was used by Fowler at the African station. For the sake of a comparison of the results, another instrument—a spectroscope, with two three-inch prisms of 60°, used in connection with a siderostat—was sent to the Brazilian station.

In all thirty-two plates were secured during totality, and twenty-two just before and after totality. With instruments of this kind, without

slits, the spectral lines become circles, or parts of circles. The H and K lines are the most conspicuous ones seen on the plates, and in them the forms of the prominences are clearly shown. The ultra-violet series of hydrogen lines is also prominent, and numerous other lines are visible, among them (on isochromatic plates) the "corona line," at λ 5317. All the plates show a bright continuous spectrum from the inner corona.

The second report is by E. H. Hills, and refers to the results obtained with the slit spectroscopes, two of which were used at each station. Only one plate was taken with each instrument, the exposure being for three minutes and fifty seconds. The plates taken in Brazil were not successful, but a large number of lines were photographed at the African station. The plates were backed with a solution of asphalt in benzole in order to prevent the reflection from the back surface of the glass.

A list is given of the wave-lengths of seventy-one lines which are assigned to the prominence spectrum, and fifty-one lines credited to the corona, the "corona line" itself being put in the former category. The wave-lengths were determined by means of an interpolation curve based upon micrometric measures of the lines of the hydrogen series, with the "lines at λ 4215.3, λ 4471.2 and the b group." The value of the results is greatly impaired by the fact that unreliable wave-lengths were assigned to the standards employed. The determinations by Huggins for the ultra-violet lines were the best at the time they were made, but they have been superseded by the measurements, with more powerful apparatus, by Cornu, Ames and others, and it seems very unfortunate that Ångström's scale should be employed in any new work. In consequence of this unhappy choice of standards the wave-lengths of the ultra-violet lines photographed at this eclipse differ in some cases as much as four tenth-meters from the values found by other observers of the prominence spectrum who base their results upon the Rowland scale. Much yet remains to be done in increasing the accuracy of our knowledge of the wave-lengths of the bright lines in the ultra-violet, but in the opinion of the reviewer the results under consideration will require re-reduction before they can be of service.

E. B. F.

Recent Publications.

A list of the titles of recent publications on astrophysical and allied subjects will be printed in each number of The Astrophysical Journal. In order that these bibliographies may be as complete as possible, authors are requested to send copies of their papers to both Editors.

For convenience of reference, the titles are classified in thirteen sections.

1. The Sun.

Brester, A., Jr. On Brester's Views as to the Tranquillity of the Solar Atmosphere. A. and A. **13**, 849–856, 1894.

Deslandres, H. On the Electric Origin of the Solar Chromosphere. Knowl. **17**, 277, 1894.

Deslandres, H. Recherches sur les mouvements de l' atmosphère solaire. C. R. **119**, 457, 1894.

Flammarion, C. Sur la rotation des taches solaires. C. R. **119**, 532, 1894. l'Astr. **13**, 421–423, 1894.

Hale, George E. On Some Attempts to Photograph the Solar Corona without an Eclipse. A. and A. **13**, 662–688, 1894.

Hazen, H. A. Sun-spots and Auroras. Am. Met. Jour. **11**, 221–229, 1894.

Hills, E. H. The Total Solar Eclipse of April 16, 1893. Report on Results Obtained with the Slit Spectroscopes. Proc. R. S. **56**, 20–26, 1894.

Lockyer, J. Norman. Preliminary Report on the Results Obtained with the Prismatic Cameras during the Total Eclipse of the Sun, April 16, 1893. Phil. Trans. **185** A, 711–717, 1894.

Wilson, W. E. and P. L. Gray. Experimental Investigations on the Effective Temperature of the Sun, made at Daramona, Streete, County Westmeath, Ireland. Phil. Trans. **185** A, 361–396, 1894.

2. The Solar Spectrum, Infra-Red, Visible, and Ultra-Violet.

Langley, S. P. On Recent Researches in the Infra-Red Spectrum. Report Oxford Meet. B. A. A. S. 1894. Nat. **51**, 12–16, 1894.

3. Stars and Stellar Photometry.

Barnard, E. E. and A. C. Ranyard. Structure of the Milky Way. Knowl. **17**, 253, 1894.

CHANDLER, S. C. Note on the Variable Star Z Herculis. A. N. **136**, 331–332, 1894.

CHANDLER, S. C. On a New Variable of the Algol-Type, 6442, Z Herculis. Astr. Jour. No. 328, **14**, 125, October 20, 1894.

CHANDLER, S. C. Ephemerides of Long-Period Variables for 1895. Astr. Jour. No. 327, **14**, 118–119, October 1, 1894.

EDITOR OF THE ASTR. JOUR. Announcement as to Two Telescopic Variables. Astr. Jour. No. 330, **14**, 144, November 23, 1894.

EDITOR OF THE ASTR. JOUR. New Variable of the Algol-Type. Astr. Jour. No. 327, **14**, 120, October 1, 1894.

GORE, J. E. Globular Star Clusters. Knowl. **17**, 232, 1894.

GORE, J. E. The Distance and Mass of the Binary Stars. Knowl. **17**, 271, 1894.

HARTWIG, ERNST. Ueber den neuen veränderlichen Stern Z Herculis. A. N. **136**, 329–332, 1894.

PANNEKOEK, A. Beobachtungen des neuen Veränderlichen Z Herculis. A. N. **136**, 221, 1894.

PARKHURST, H. M. Stellar Photometry. A. and A. **13**, 652-659, 1894.

PARKHURST, J. A. Maxima and Minima of Long-Period Variables. Astr. Jour. No. 331, **14**, 151, December 10, 1894.

PLASSMAN, J. Beobachtungen von Z Herculis in Warendorf. A. N. **136**, 333–334, 1894.

RANYARD, A. C. Photographs of the Milky Way and Nebulæ. Knowl. **17**, 226, 1894.

REED, WILLIAM MAXWELL. Observations of Variable Stars. Astr. Jour. No. 330, **14**, 137–141, November 23, 1894.

ROBERTS, A. W. New Short-Period Variable. Astr. Jour. No. 327, **14**, 120, October 1, 1894.

ROBERTS, A. W. Variation of (3416)—Velorum and (5949)—Aræ. Astr. Jour. No. 327, **14**, 113–117, October 1, 1894.

SAWYER, EDWIN F. On the Variability of 6442 Z Herculis. Astr. Jour. No. 329, **14**, 135, November 9, 1894.

SAWYER, EDWIN F. On the Variable Star 6573 Y Sagittarii. Astr. Jour. No. 328, **14**, 127–128, October 20, 1894.

YENDELL, PAUL S. On the Variability of DM. $+ 15^\circ$ 3311. Astr. Jour. No. 328, **14**, 125, October 20, 1894.

YENDELL, PAUL S. Observed Maxima of Long-Period Variables, with Note on a Suspected New Variable. Astr. Jour. No. 328, **14**, 121–122, October 20, 1894.

YENDELL, PAUL S. On a New Variable of Short Period. Astr. Jour. No. 331, **14**, 150, December 10, 1894.

YENDELL, PAUL S. Observations of Suspected Variables. Astr. Jour. No. 329, **14**, 133–134, November 9, 1894.

4. Stellar Spectra, Displacements of Lines and Motions in the Line of Sight.

Belopolsky, A. Das Spectrum von δ Cephei. A. N. **136**, 281–284, 1894.

Espin, T. E. The Spectrum of α Herculis. A. and A. **13**, 651, 1894.

Lockyer, J. Norman. The Spectrum Changes in β Lyræ. Proc. R. S. **56**, 278–285, 1894.

5. Planets, Satellites and their Spectra.

Barnard, E. E. The Great Red Spot and other Markings on Jupiter. A. and A. **13**, 736, 1894.

Barnard, E. E. The Form of the Disk of the III Satellite and Phenomena of the Occultation of a Satellite of Jupiter. A. and A. **13**, 821, 1894.

Bigourdan, G. Disparition de la tache polaire australe de Mars. C. R. **119**, 633, 840, 1894.

Cerulli, V. Una macchia sul lembo nord di Marte. A. N. **136**, 223, 1894.

Campbell, W. W. The Spectrum of Mars. Pub. A. S. P. **6**, 228, 1894. A. and A. **13**, 752–760, 1894.

Douglass, A. E. The Polar Cap of Mars. A. and A. **13**, 738, 1894.

Elger, T. Gwyn. The Central Equatorial Region of the Moon. Knowl. **17**, 276, 1894.

Elger, T. Gwyn. Selenographical Notes. Obs'y **17**, 266, August, 1894; 332, October, 1894; 357, November, 1894.

Flammarion, C. Les neiges polaires de Mars. C. R. **119**, 786–791, 1894.

Flammarion, C. Sur les pôles de rotation de Vénus. C. R. **119**, 670, 1894.

Flammarion, C. Observations de la planète Mars, faites à l' Observatoire de Juvisy. l' Astr. **13**, 376–385; 408–413, 1894.

Franz, J. Der Einfluss der Phase auf die scheinbare Lage von Mösting A. A. N. **136**, 321–330, 1894.

Gaudibert, C. M. Photographie lunaire. Clavius. l' Astr. **13**, 413–419, 1894.

Gruey, L. J. Observation de l' éclipse partielle de Lune 1894, Septembre 14, faite à l'Observatoire de Besançon. A. N. **136**, 285–286, 1894.

Lowell, Percival. Mars. A. and A. **13**, 538–553, 645–650, 740–741, 814–821, 1894.

Marth, A. Ephemeris for Physical Observations of Jupiter, 1894–5. M. N. **54**, 562, 594, 1894.

Maunder, E. W. The Canals of Mars. Knowl. **17**, 249, 1894.

PICKERING, W. H. Schiaparelli's Latest Views Regarding Mars. A. and A. **13**, 632–635, 1894.

RISTENPART, F. and MIE, G. Beobachtung der partiellen Mondfinsterness, 1894, September 14, zu Karlsruhe. A. N. **136**, 283–286, 1894.

SCHÆBERLE, J. M. The Region of Lacus Solis on Mars. A. and A. **13**, 644, 1894.

SCHIAPARELLI, G. The Planet Mars. A. and A. **13**, 635–640, 714–722, 1894.

TROUVELOT, E. L. Passage de Mercure devant le Soleil. C. R. **119**, 842, 1894.

WILLIAMS, A. STANLEY. Notes on Mars, 1894. Obs'y **17**, 319–321, October, 1894; 347–349, November, 1894.

YOUNG, C. A. Transit of Mercury, 1894, November 10. Astr. Jour. No. 330, **14**, 143, November 23, 1894.

6. COMETS, METEORS AND THEIR SPECTRA.

BARNARD, E. E. Photographs of a Remarkable Comet. A. and A. **13**, 789, 1894.

DENZA, P. F. Les étoiles filantes observées en Italie au mois d'août, 1894. C. R. **119**, 508, 1894. l'Astr. **13**, 419, 1894.

MALTÉZOS, C. Sur la chute des bolides et aérolithes tombés dernièrement en Grèce. C. R. **119**, 500, 1894. l'Astr. **13**, 386, 1894.

WESLEY, W. H. The Comet on the Eclipse Photographs of 1893. Obs'y **17**, 349–353, November, 1894.

7. NEBULÆ AND THEIR SPECTRA.

BARNARD, E. E. Photograph of M. 8 and the Trifid Nebula. A. and A. **13**, 791, 1894.

BARNARD, E. E. Photograph of Swift's Nebula in Monoceros. N. G. C. 2237. A. and A. **13**, 642–644, 1894.

BARNARD, E. E. The Great Photographic Nebula of Orion, Encircling the Belt and Theta Nebula. A. and A. **13**, 811–814, 1894.

BARNARD, E. E. On the Exterior Nebulosities of the Pleiades. A. N. **136**, 196, 1894. A. and A. **13**, 768–770, 1894.

EASTON, C. The Great Nebula in Andromeda. Nat. **50**, 547, October 4, 1894.

LOCKYER, J. NORMAN. On the Photographic Spectrum of the Great Nebula in Orion. Proc. R. S. **56**, 285, 1894.

8. TERRESTRIAL PHYSICS.

BIGELOW, F. H. Inversion of Temperatures in the 26.68-day Solar Magnetic Period. Am. Jour. [3] **48**, 435–451, 1894.

Culverwell, Edward, P. A Criticism of the Astronomical Theory of the Ice Age. Nat. **51**, 33–34, November 8, 1894.

Culverwell, Edward P. A Mode of Calculating a Limit to the Direct Effect of Great Eccentricity of the Earth's Orbit on Terrestrial Temperatures, Showing the Inadequacy of the Astronomical Theory of Ice Ages and Genial Ages. Phil. Mag. [5] **38**, 541–552, December, 1894.

9. Experimental and Theoretical Physics.

Abney, W. de W. Measurement of Color Produced by Contrast. Proc. R. S. **56**, 221–229, 1894.

de Muynck, R. Ueber die Brechungsexponenten von wässerigen Cadmiumsalzlösungen. Wied. Ann. No. 11, **53**, 559–563, 1894.

Nichols, E. L. and Mary L. Crehore. Studies of the Lime Light. Phys. Rev. **2**, 161–170, 1894.

Paschen F. Ueber die Dispersion des Steinsalzes im Ultraroth, Wied. Ann. No. 10, **53**, 337–342, 1894.

Paschen, F. Ueber die Dispersion des Fluorits im Ultraroth. Wied. Ann. No. 10, **53**, 301–333, 1894.

Pictet, Raoul. Étude sur le rayonnement aux basses temperatures; applications à la thérapeutique. Arch. de Genève **32**, 233–254, 465–480, 1894.

Rubens, H. Prüfung der Ketteler-Helmholtz'schen Dispersionsformel. Wied. Ann. No. 10, **53**, 267–286, 1894.

Sharp, C. H. and W. R. Turnbull. A Bolometric Study of Light Standards. Phys. Rev. **2**, 1–35, 1894.

Salomons, David. On some Phenomena in Vacuum-Tubes. Proc. R. S. **56**, 229–250, 1894.

Thomas, L. Sur la constitution de l'arc électrique. C. R. **119**, 728, 1894.

10. The Spectra of the Elements.

Crew, Henry and R. Tatnall. On a New Method for Mapping the Spectra of Metals. Phil. Mag. **38**, 379–386, 1894. A. and A. **13**, 741–747, 1894.

Ewan, Thomas. On the Absorption Spectra of Dilute Solutions. Proc. R. S. **56**, 286, 1894.

Hartley, W. N. Flame Spectra at High Temperatures, Part II. The Spectrum of Metallic Manganese, of Alloys of Manganese, and of Compounds Containing that Element. Proc. R. S. **56**, 192, 1894.

Hartley, W. N. Flame Spectra at High Temperatures. Part III. The Spectroscopic Phenomena and Thermo-Chemistry of the Bessemer Process. Proc. R. S. **56**, 193–196, 1894.

HASSELBERG, B. On the Line Spectrum of Oxygen. Wied. Ann. No. 8, 1894. A. and A. **13**, 760–763, 1894.

LEWIS, E. P. and E. S. FERRY. The Infra-Red Spectra of Metals. J. H. Univ. Circ. No. 12. A. and A. **13**, 747–752, 1894.

PASCHEN, F. Bolometrische Arbeiten. Wied. Ann. No. 10, **53**, 287–300, 1894.

PASCHEN, F. Die genauen Wellenlängen der Banden des ultrarothen Kohlensäure und Wasserspectrums. Wied. Ann. No. 10, **53**, 334–336, 1894.

11. PHOTOGRAPHY.

MELDOLA, R. The Optics of Photography. Review of Vogel's Handbuch der Photographie, II. Theil. Nat. **50**, 589–590, October 18, 1894.

12. INSTRUMENTS AND APPARATUS.

DESLANDRES, H. Sur l'enregistrement de la chromosphère et de la photosphère du Soleil par la méthode des sections successives. Bull. Astr. **11**, 425–426, October, 1894.

ELKIN, W. L. Instrument for the Photography of Meteors. A. and A. **13**, 626, 1894.

HOWE, H. A. The 20-inch Equatorial of the Chamberlin Observatory. A. and A. **13**, 709–714, 826–830, 1894.

NICHOLS, E. L. A New Form of Spectrophotometer. Phys. Rev. **2**, 138, 1894.

PULFRICH, C. Ueber eine neue Spektroskop-Konstruktion. Z. f. Instrum. **14**, 354–364, 1894.

RIEFLER, S. Beschreibung des Echappements mit vollkommen freien Pendel. Z. f. Instrum. **14**, 346, 1894.

SIRKS, J. L. On the Astigmatism of Rowland's Concave Gratings. Ver. K. Akad. v. Wetens, **2**. A. and A. **13**, 763–768, 1894.

WADSWORTH, F. L. O. Improved Form of Interrupter for Large Induction Coils. Am. Jour. [3] **48**, 496–501, 1894.

WADSWORTH, F. L. O. Eine neuer Spektroskopspalt mit Doppelbewegung. Z. f. Instrum. **14**, 364, 1894.

WADSWORTH, F. L. O. Some New Forms of Double Motion Mechanism. A. and A. **13**, 527–538, 1894.

WADSWORTH, F. L. O. A Simple Method of Mounting an Equatorial Axis on Ball Bearings. A. and A. **13**, 723–728, 1894.

WADSWORTH, F. L. O. Fixed-Arm Spectroscopes (The Modern Spectroscope, IX.). Phil. Mag. **38**, 337–351, October, 1894; A. and A. **13**, 835–849.

————. The Buckingham Works, York (Cooke's Equatorial Mountings). Engineering **58**, 660–665, 1894.

13. General Articles, Memoirs and Serial Publications.

Blanshard, C. T. New Element in the Sulphur Group. Nat. **50,** 571, October 11, 1894.

Dreyer, J. L. E. Astronomical Spectroscopy; A Review of Frost's translation of *Die Spectralanalyse der Gestirne.* Nat. **50,** 565–567, October 11, 1894.

Dyson, F. W. Note on Professor Turner's paper on the Reduction of Measures of Photographic Plates. M. N. **54,** 573, 1894.

Hale, George E. The Astrophysical Journal. A. and A. **13,** 831–835, 1894.

Keeler, James E. Professor Frost's Translation and Revision of *Die Spectralanalyse der Gestirne.* A. and A. **13,** 668, 1894.

Lohse, O. Planetographie. Eine Beschreibung der im Bereiche der Sonne zu beobacht. Körper, 8vo. **1**, ix + 192, 15 cuts. Weber, Leipzig, 1894.

Mendenhall, T. C. Measurements of Precision; An address delivered at the Johns Hopkins University, Baltimore. Nat. **50,** 584–587, October 11, 1894.

Michelson, A. A. Determination experimentale de la valeur du mètre en longueurs d'ondes lumineuses. Mem. du Bur. Int. des Poids et Mesures **11,** 1894.

Müller, G. and P. Kempf. Publicationen des Astrophysikalischen Observatoriums zu Potsdam, Nr. 31. Neunter Band. Photometrische Durchmusterung des nördlichen Himmels, enthaltend alle Sterne der B. D. bis zur Grösse 7.5. Theil I., Zone 0° bis + 20° Declination. Potsdam, 1894.

Strehl, Karl. Die Theorie des Fernrohrs auf Grund der Beugung des Lichts. I. Teil, viii.+136, 1 plate, 8vo, 1894. J. A. Barth, Leipzig,

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PLATE VI

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